MECHANICAL PROCESSES

—DANFORTH

MECHANICAL PROCESSES

AN ELEMENTARY OUTLINE OF

MECHANICAL PROCESSES

GIVING A BRIEF ACCOUNT OF
THE MATERIALS USED IN ENGINEERING CONSTRUCTION AND OF THE
ESSENTIAL FEATURES IN THE METHODS OF PRODUCING THEM,
ALSO DESCRIBING SHOP PROCESSES AND EQUIPMENT
FOR THE SHAPING OF METALS INTO FORMS
FOR ENGINEERING AND GENERAL USES

ARRANGED FOR THE INSTRUCTION OF MIDSHIPMEN AT THE U. S. NAVAL ACADEMY
AND FOR STUDENTS IN GENERAL

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PREFACE

This book is intended as an elementary account of the several classes of processes employed in shaping materials of construction for various mechanical uses. A brief account of the properties of these materials and of the methods of producing them is also given.

Effort has been made to present the subject matter in brief and elementary form, with sufficient detail to outline methods and principles clearly. It is intended to show completely, though briefly, the steps of metal manufacture from the ore to the finished product, so that the student may be enabled to classify all branches of metal manufacture, and may pursue intelligently such study as will give fuller information than is possible to include herein.

Most of the subject matter is from notes taken by the writer when on engineering instruction, on shipyard inspection and other engineering duty and during recent visits to manufacturing plants where processes were observed through the courtesy of officials of those plants, and where valuable information was obtained which could not be obtained otherwise. These notes were in several instances checked and supplemented by information from various technical books and papers, particularly by reference to their reports of original investigations. A list of the books of great assistance in this work is as follows:

Iron (The Metallurgy of)—Turner.
Steel (The Metallurgy of)—Harbord and Hall.
The Metallurgy of Iron and Steel—Stoughton.
Chemistry of Materials of Engineering—Sexton.
Elementary Text Book of Metallurgy—Sexton.
Materials of Engineering—Thurston.
The Materials of Construction—Johnson.
Calcareous Cements—Redgrave and Spackman.
Hawkins Mechanical Dictionary.
Cyclopædia of Mechanical Engineering.
Journal of the American Society of Naval Engineers.

The shops of the following named industrial companies were recently visited:

Acme Steel & Malleable Iron Works, Buffalo, N. Y.
American Iron and Steel Mfg. Co., Reading, Pa.
American Sheet and Tin Plate Co., Pittsburgh, Pa.
American Steel and Wire Co., Springfield, Mass.
American Welding Co., Carbondale, Pa.
Babcock and Wilcox Boiler Co., Bayonne, N. J.
Benedict and Burnham Mfg. Co., Waterbury, Conn.
Best Mfg. Co., Pittsburgh, Pa.
Bethlehem Steel Co., South Bethlehem, Pa.
Billings and Spencer Co., Hartford, Conn.
E. W. Bliss Co., Brooklyn, N. Y.
Brown & Sharpe Mfg. Co., Providence, R. I.
The Carborundum Co., Niagara Falls, N. Y.
The Coe Brass Mfg. Co., Ansonia, Conn.
Cramp & Sons Ship and Engine Bldg. Co., Philadelphia.
The Crosby Co., Buffalo, N. Y.
Fore River Ship and Engine Bldg. Co., Quincy, Mass.
Glasgow Iron Works, Pottstown, Pa.
C. G. Hussey & Co., Pittsburgh, Pa.
Midvale Steel Co., Wayne Junction, Pa.
National Tube Co.'s Works at
    Christy Park, Pa.
    McKeesport, Pa.
    Elwood City, Pa.
New York Shipbuilding Co., Camden, N. J.
Nicholson File Co., Providence, R. I.
Niles-Benent-Pond Co., Philadelphia, Pa.
  and branches
    Pond Machine Tool Co., Plainfield, N. J.
    Pratt & Whitney Co., Hartford, Conn.
Reading Steel Castings Co., Reading, Pa.
Schutte and Koerting Co., Philadelphia, Pa.
Seneca Iron and Steel Co., Buffalo, N. Y.
Worth Bros. Iron Works, Coatesville, Pa.
U. S. Navy Yard, New York, N. Y.
U. S. Navy Yard, Boston, Mass.

In addition, the following named companies have contributed useful information:

Harbison Walker Refractories Co., Pittsburgh, Pa.
Illinois Steel Co., South Chicago, Ill.
C. W. Leavitt & Co., New York, N. Y.
Manning, Maxwell and Moore, New York, N. Y.
Oliver Machinery Co., Grand Rapids, Mich.
Rockwell Furnace Co., New York, N. Y.
United Engineering and Foundry Co., Pittsburgh, Pa.

The manuscript was read by Captain F. W. Bartlett, U. S. Navy, Head of the Department of Marine Engineering and Naval Construction at the Naval Academy, and many valuable suggestions made by him are embodied in the text.

G. W. DANFORTH, U. S. Navy.

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CHAPTER I.

INTRODUCTORY. ENGINEERING MATERIALS.

1. Scope of Mechanical Processes.—Mechanical processes properly include every manual and machine process, and the mechanical part of every chemical process, used in the extensive field of the mechanical arts. This broad field includes every branch of manufacturing and construction. It would be obviously impracticable to attempt to cover this field in one book, hence it is intended to include here a brief account of (1) the more important materials of construction and the essential steps in producing them; and (2) the methods of shaping metals for use, particularly the shop processes much used in mechanical and marine engineering construction.

To give a full account of all that investigators have brought to light of the properties of the commonly used engineering materials, and of all the methods devised for shaping them into useful forms, would require the space of many volumes, and then the subject would not be exhausted, as doubtless many facts and methods are yet undeveloped. Attempt is made herein to give the student an elementary understanding of the materials and methods employed in machine building, for use of those who enter or must come into intelligent contact with modern engineering.

2. Study of Processes.—Every process involves time, labor, and expense, and is employed in whole or in part only because it accomplishes a definite and necessary purpose. Its use must be justified as a necessary step toward a definite result, else there would be no reason for employing it. A process may not be perfect, although it may bring excellent results, and improvements in processes are being made constantly, despite the remarkable degree of skill at present existing in the production and shaping of metals for a great variety of uses.

From a superficial knowledge of the properties of metals, many remarkable processes of shaping them hot or cold have been gradu-

ally evolved or improved upon by patient and persistent experiments, and methods for shaping metals are now in vogue which were deemed impossible a decade ago. Success along these lines comes only from testing the properties of a material beyond the known range, studying the causes of failure, and bringing to one's aid improved apparatus for holding, pressing, cutting, heating, etc., as necessity may require.

The details of many processes vary because of difference in the skill of workmen, or difference in equipment or quality of materials with which they work.

3. General Classification of Materials.—The materials used in all branches of construction are commonly called engineering materials or materials of construction. The most important of these, as iron, steel, brass, wood, stone, etc., are well known. There are many other materials less extensively used, and more or less widely known.

Another class of materials necessary to the various processes include those employed to assist the processes, though not intended to enter into the finished product, as fuel, flux in smelting and in welding, emery in grinding, sand in moulding, etc.

4. Materials Most Used.—The material most extensively used in engineering construction is iron in its several forms, included under three divisions, viz., wrought iron, steel and cast iron. The materials of these three divisions are made the subjects of a subsequent chapter. Other materials, of varying degrees of importance, are:

Alloys,	Nickel,
Copper,	Aluminum,
Zinc,	Antimony,
Tin,	Portland cement.
Lead,	Wood.

5. Properties of Materials.—All materials have certain physical properties which determine their fitness for specific purposes. Of first consideration in materials of construction is strength, or tenacity, which is the attraction between molecules of a material giving them the power to resist tearing apart. Next in consideration is the property of a material which allows a change of relative position of its molecules (which is change of shape), without destroying or seriously affecting tenacity.

Specific properties of materials are:

(1) Hardness, the property of resisting change of shape under pressure and separation into parts.

(2) Brittleness, associated with hardness, the property of resisting a change of the relative position of molecules, or liability to fracture without change of shape.

(3) Density, the weight of a unit volume usually compared with unit volume of water.

(4) Elasticity, the power of returning to the original shape upon removal of the force which has caused change of shape.

(5) Ductility, the property of metals allowing them to be drawn out, as in wire-making, without breaking.

(6) Malleability, similar to ductility, the property of metals allowing them to bend or be permanently distorted without rupture. Examples of this are rolling a metal into sheets or changing its form by hammering. Opposed to brittleness.

(7) Fusibility, the property of being liquefied by heat.

(8) Conductivity, the power to transmit molecular vibrations caused by heat or electricity.

(9) Contraction and expansion, the change of volume due to change of temperature.

6. Influences Which Change Properties of Materials.—Heat has more or less influence in changing these properties in a given material.

Hardness and strength are increased by hammering or rolling a metal, and these properties are changed, often in a marked degree, by a slight amount of another substance in the metal.

Conductivity is usually increased or decreased by heat, and electric conductivity is greatly reduced by impurity in metals.

Some metals and alloys expand upon cooling, due to certain ingredients.

Heating and cooling suddenly, will render steel hard and brittle, and *annealing,* which is a different process for different metals, brings a metal or an alloy back to its natural or normal state of softness after having been hardened by hammering, rolling, or otherwise.

7. Fatigue of Metals.—It has been found that metals give way in some cases under smaller loads than they could originally carry.

This is called *fatigue,* and is caused by a very great number of reversals or repetitions of load, as when a metal receives constant shocks or impacts in use. It is a popular but erroneous idea that the particles of metal change to a weakened crystalline form. Later investigations show that the loss of strength is due to the crystals of metal being so shaken that the small planes of cleavage between them join in one continuous plane of rupture, which, when sufficiently extended, leaves the remaining sound metal unable to resist the shock brought upon it. Cases of fatigue are unusual.

8. Classification of Forces.—Forces acting upon materials are classified according to their direction of action.

A force acting on a material is called a *stress,* and the deformation caused by this action is the consequent *strain.*

If, upon removal of the force, the material returns to its original shape, the strain has been within the *elastic limit* of the material,

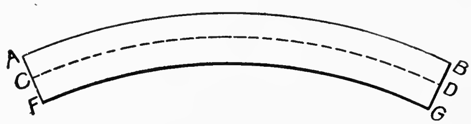


FIG. 1.

but if upon removing the force, the material fails to resume its original shape, it has been strained beyond its elastic limit, and is said to have a *permanent set.* If the force continues to be increased beyond that causing permanent set, a rupture of the material will finally result.

Tension is the action of forces tending to pull apart the particles of a material, and *tensile strength* of a material, expressed in pounds per square inch of cross section of the material pulled, is a measure of the force required to disrupt the material. The amount which a metal stretches in pulling apart is called the *elongation.* This is expressed as a per cent of the original length of the metal specimen subjected to tension.

Compression is the crushing action of forces.

Torsion is the twisting action of forces.

Shearing is the action of forces tending to cause adjacent parts of a material to move in opposite directions parallel to a plane of cleavage.

To illustrate the result of bending, consider that a piece of material is bent as shown in Fig. 1. Its fibres or particles along AB, and for a distance thereunder, are in tension and are slightly elongated, while fibres or particles along FG, and for a distance above, are in compression, and are slightly shortened.

There is a portion of the piece along CD which is neither under tension nor compression and remains of unchanged length. This is called the *neutral axis.*

9. Alloys.—An alloy is a combination formed by stirring together two or more metals (occasionally with other substances introduced) in a state of fusion. Investigators state that some alloys are chemical combinations, some are mechanical mixtures and others are apparently solutions of one metal in another.

10. Peculiarities of Alloys.—Alloys have peculiarities demanding special and extensive study to understand them, and no laws have yet been found by which the properties of an alloy may be determined from the properties of its constituents. The properties of an alloy are not an average of like properties in its constituents, and very unexpected results may be obtained by varying the proportions of constituents of an alloy, or by introducing the slightest amount of some other ingredient.

The following items give the important peculiarities of alloys:

(1) The strength of some alloys, particularly when hammered, rolled or drawn into wire, is much greater than that of any of the composing metals. This is true of the useful brasses and bronzes.

(2) Varying the proportions of the same metals in an alloy throughout a wide range will give very different products in strength, hardness, malleability, ductility, density, fusion point, and color. These changes will not come in a line of regularity. Some of the products will differ widely from the rest.

(3) The fusing point of an alloy is usually lower than the average of the fusing points of the constituents, and sometimes lower than the fusing point of any constituent. Some alloys, composed of about 50% of bismuth, melt below the temperature of boiling water.

(4) The introduction of a slight amount of some metals, metalloids or impurities in a given alloy may bring great changes to one

or more of its properties, sometimes improving the alloy, but more frequently rendering it worthless.

(5) The order of melting and mixing the several metals of an alloy influences the quality of the alloy, because some metals oxidize more readily than others in the fused state. This oxidation should be reduced to a minimum because it wastes the metal and the oxide weakens the alloy.

In making alloys, it is needless to attempt to get good results by using any but the purest of commercial metals, and scrap alloys may be used only when their composition is known and when it is suitable to the correct proportioning of the mixture to be made.

The principal requirements in melting metals for alloys are (1) melt the metal of highest fusion point, and, when melted, drop in the other metal broken up in chunks; (2) have the molten surface of metal covered with salt or other flux, or with charcoal, to prevent oxidation from atmospheric oxygen; (3) stir the metals well with an iron rod before pouring from the crucible.

If the metals in an alloy are not thoroughly mixed, they may not form a homogeneous mass upon cooling. The separating out of any masses of one of the metals is called *liquation*. This condition will not likely show on the surface of the alloy when cold, but will affect strength and other qualities.

11. Designations of Well-Known Alloys.—The most extensively used of all alloys are those consisting mainly of copper. Their ornamental appearance and non-corrosive quality make them desirable, and their strength, with varying degrees of hardness, elasticity, ductility and malleability, supplies the requirements for materials of a wide range of use.

In general, copper-zinc alloys are called *brass,* although some brass may contain also a small amount of lead or tin; copper-tin alloys are the main constituents of *bronze;* and copper-tin-zinc alloys are known as *composition.* These terms, as will be learned, are loosely used in practice and not confined to the designations here given.

12. Brass.—This is one of the most important of the alloys. While its usual constituents, copper and zinc, combine in any proportion, the range of useful proportions varies from about 60 to

89% of copper. A widely used formula for brass is about 2/3 copper and 1/3 zinc.

The range of composition of brass offers a material suitable for a great number of particular uses. Zinc gives brass its hardness, and tin in small quantities increases this. Experiment shows that the tensile strength of cast brass is greatest (about 50,000 lbs. per sq. in.) when the composition is about 62% copper and 38% zinc; and that ductility and malleability are greatest for about 70% copper and 30% zinc. These properties, however, are improved by adding a small amount of tin for hardness, or lead for ductility.

Brass may be considerably hardened by rolling or hammering, hot or cold, or by drawing it into wire. Its strength and rigidity are by these means increased, and brass thus treated is used for springs, but these effects may be removed by annealing, which consists of heating to a cherry-red and cooling slowly, or rapidly, if its composition will not cause cracking. Thoroughly annealed brass has no springiness and may be bent like lead.

13. The Bronzes.—Phosphor, manganese and aluminum bronzes are among the best bronzes known, and are the most extensively used. Bronzes are used when a strong and fairly ductile non-corrosive alloy is necessary in ship and machinery parts. They are the strongest and about the most expensive alloys in engineering use. Phosphorus and manganese are used in the bronzes designated by these names merely to assist in purging the molten mixtures of metallic oxides, thus producing alloys of greater metallic purity and consequently of greater strength.

Aluminum and copper seem to form a chemical union of remarkable strength and ductility, having properties resembling those of mild steel. The alloy can be forged at a red heat, it makes excellent castings, its strength is greatly increased by hammering or rolling, and it resists the corrosive action of air and salt water.

Generally, the bronzes can be considerably strengthened by hammering or rolling, can be forged hot, (but not welded in a blacksmith forge), and their hardness increases as the per cent of copper is lessened, while ductility increases as the copper is increased. The less ductile mixtures should be rolled or worked hot. A peculiarity of the copper-tin alloys is that quick cooling in water tends to re-

move brittleness and to increase ductility and softness, while slow cooling from a red heat restores the original hardness.

The bronzes are less ductile than brass, and those to be rolled into sheets or drawn into wire must not contain as much tin as those to be cast. Their hardness makes them excellent for machinery bearings. Propellers and many ship fittings are made of bronze because of its strength and resistance to salt water corrosion.

14. Other Useful Alloys in engineering work are:

Anti-Friction Metal, used to line bearings for shafts; composed of

Best refined copper............	3.7	per cent
Banca tin	88.8	" "
Regulus of antimony..........	7.5	" "

These must be well fluxed with borax and rosin in mixing.

Monel Metal, for blades of steam turbines.

Nickel, not less than 60 per cent;
Copper, remainder to make up 100 per cent.

A monel metal consisting of nickel, copper, and iron is refined from a deposit of natural alloy of these metals. It is much cheaper than the made-up alloy and is well adapted to practical use, although its proportions are not likely to be always the same.

Another alloy recently brought into use consists of

Aluminum	90	per cent
Magnesium	10	" "

This alloy is lighter and stronger than aluminum, and will doubtless find extensive use in airship construction, and possibly for castings for submarine and other naval uses, where lightness and strength are requisite features.

15. Copper. Its Uses.—Copper is next in importance to iron as a metal of the useful arts, though it is used mostly in alloys. Its principal uses are:

(1) As the main constituent of most of the useful alloys.

(2) For pipes and tubes to convey steam and liquids. A coating of tin is frequently given copper pipes and tubes used to convey liquids to aid in resisting corrosion.

(3) As wire for resisting corrosion and particularly for electric conductors because of its high degree of conductivity when pure.

(4) For sheathing and fastenings of wooden ships.

16. Properties of Copper.—The color of copper is dull red. In malleability and ductility, either hot or cold, it ranks very high. Its tensile strength is about 30,000 lbs., although rolling, hammering or drawing it into wire nearly doubles its strength. It fuses at about 1985° F. The most striking properties of copper are, (1) the adverse way in which the smallest amount of impurity affects it, and (2) its superior conductivity for heat and electricity when pure (99.9%).

It is easily forged or rolled hot or cold and when worked cold it becomes hard, as in wire drawing, but it may be again softened, or annealed, by heating to red heat and plunging into cold water, which also causes a loss of the tensile strength gained by working.

Commercial copper is often very impure, containing arsenic, antimony, copper oxide, iron, and lead, according to the ores from which extracted. This must be refined, and should then be 99.8% pure for high grade uses. Refineries supply copper for market in (1) "pigs" for melting and making alloys, (2) slabs for rolling into sheets for various uses, and (3) ingots for wire or tube-drawing.

17. Uses of Zinc.—The principal uses for this metal are as follows:

(1) The most important use is for alloying with copper in making brass or composition.

(2) When zinc is exposed to air or water, a durable and impermeable coating of zinc carbonate is formed on the surface of the metal. This makes it useful for galvanizing iron to protect against rusting. Zinc sheets may be used for sheathing or roofing.

(3) Zinc is the most electro-positive of the common metals. This makes it particularly useful as a protection against galvanic corrosion in steam boilers, and on the hulls of steel ships. Copper, brass and bronze may also be protected by its use. Rolled zinc slabs are bolted in scraped metallic contact with the part to be protected, and the electrolytic action of impure water in which the metals are immersed gradually corrodes the zinc, leaving the protected metal intact. However, when the zinc becomes much corroded and its

metallic surface is no longer exposed, the zinc compound resulting from the corrosion acts electro-negative to the protected metal and this metal is itself destroyed. The protection of iron by galvanizing, as mentioned in item (2), is due not only to a coating of zinc but to the fact that when a part of the zinc coating is broken and the iron is exposed, dampness sets up an electric current which consumes the zinc instead of the iron.

(4) Zinc plates are used extensively in electric batteries.

(5) Oxide and sulphide of zinc are used to make a superior grade of white paint.

18. Properties of Zinc.—Zinc has a bluish-white color. Its malleability and ductility are confined to certain narrow limits of temperature, and it must be maintained at a temperature of about 240° F. when it is being rolled into sheets. It melts at about 800° F., and boils at about 1900° F. It is hard, brittle and highly crystalline in fracture, and if the fracture shows dull specks, an excess of iron is present. Rolled zinc is more dense than the cast metal, and can be bent to a moderate degree.

Commercial zinc is known as spelter, and its impurities are mostly lead and iron.

19. Uses of Tin.—(1) The most important engineering use of this metal is in alloys.

(2) It is used extensively for coating sheets of iron to prevent corrosion, and these sheets are widely known as "tin"; also it is used to coat copper, brass and iron wire, pipes, and tubes, by dipping them into melted tin.

(3) It is used as an ingredient of solder and brazing metal.

20. Properties of Tin.—Tin has nearly the whiteness of silver. It is very malleable and flexible, but not elastic. Its tensile strength is too low for it to be drawn into wire. Air will not tarnish it readily, but some acids and strong alkaline solutions attack it noticeably, particularly when hot.

It is a poor conductor of heat and electricity. When pure, a bar or sheet of tin makes a crackling sound when bent, called the "cry of tin," and as this sound is destroyed by lead as an impurity, this fact is often made use of in testing tin. It melts at about 445° F.

Tin is marketed in small ingots, and is known as "Straits," "Banca," "Malacca," "Australian," etc., according to its source.

Its usual impurities are lead, iron, copper, and antimony. Good tin should be 99.75% pure.

21. Uses of Lead.—This metal has several minor uses in engineering. Of these the principal uses are:

(1) As sheet lead for lining tanks and basins because of its power to resist corrosion from air and from many dilute acids.

(2) As pipes in plumbing work due to its flexibility, ease of soldering, and qualities mentioned in item (1), although it cannot stand high heat or high pressure.

(3) As wire for gaging tightness of large engine bearings, and for electric fuses.

(4) As pigments for well-known paints in the form of "red lead" (oxide of lead), and of "white lead" (lead carbonate).

(5) Occasionally for alloying in small quantities with other metals to increase ductility and malleability.

22 Properties of Lead.—Lead has a blue-gray color. It is the softest and heaviest of the common metals. It is very malleable and ductile, but has no elastic strength, and its tensile strength is so low that it cannot be drawn readily into fine wires. It is a poor conductor of heat and electricity. On account of its softness it can be readily squeezed through a press and thus shaped into rods or pipes. It melts at about 600° F.

The best grade of commercial lead should be 99.5% pure.

23. Uses of Nickel.—(1) A very important engineering use for this metal is in alloy with steel. Its addition to mild steel gives a product of great elastic and tensile strength and fair ductility. Its presence in steel lessens corrosion.

(2) Another alloy of nickel of importance is monel metal.

(3) The use of nickel for plating metal articles is well known.

(4) In commercial alloys, principally German silver, nickel is extensively used; also an alloyed nickel is used for small coins.

24. Properties of Nickel.—Nickel is white with a bluish tinge. It is malleable and ductile It has about the same hardness and fusion point as iron, and is heavier than iron, to which it is closely related, having magnetic properties.

25. Uses of Aluminum.—The principal uses of aluminum are in making aluminum bronze, and as pressed sheet or cast aluminum

for various utensils and fittings where extreme lightness and fair strength are required.

26. Properties of Aluminum.—This metal presents a remarkable combination of qualities. It is the lightest of the useful metals (excepting magnesium, which has only limited uses as a metal), has many exceptional uses, is more abundant in nature than any other known metal, and is extracted by a process quite apart from general metal extraction methods.

Its physical qualities are as follows:

Color, silvery white.

Malleability and ductility, slightly less than that of copper.

Tensile strength, varying from about 16,000 lbs. for cast metal to about 25,000 lbs. for rolled metal. Annealing slightly decreases the strength of rolled metal.

Fusing point, about 1200° F.

Specific gravity, about 2.6, or about ⅓ the weight of iron.

It is an excellent conductor of heat and electricity, does not corrode in air or in water to a noticeable degree, but it can be soldered only with much difficulty due to the fact that the pure metallic surface quickly unites with oxygen, forming a film on which the solder will not hold.

Aluminum is not so soft as copper, and when hammered assumes the hardness of hard brass, although annealing (heating to a red heat and cooling slowly) again renders it pliable.

In melting it for castings, an ordinary crucible should be used, but flux should not be used because of the chemical combination likely to result. It shrinks much on cooling.

27. Use and Properties of Antimony.—In engineering uses this metal serves as a hardening constituent for anti-friction alloys. It also causes these alloys to expand after they are poured into place, making them fill completely, when cold, the space intended for them. It is grayish white, extremely brittle, has a peculiar odor, and melts at about 850° F.

Its usual commercial form, the regulus of antimony, is a somewhat impure metal extracted from its compound with sulphur.

28. Portland Cement. General Characteristics.—This material having been perfected within recent years, has many important uses. It is supplied commercially in a very finely ground state,

and, when mixed with water alone, or when mixed with water and definite proportions of sand, gravel, or broken stone, it can be moulded to any form desired and will gradually harden in air or under water in the form to which it is moulded. When used in this way it is popularly known as concrete or béton.

29. Varieties of Lime and Cement.—The many forms of lime and building cement consist mostly of calcium oxide (CaO), which is formed from calcium carbonate ($CaCO_3$) by calcination. These forms merge one into another according to the kinds and amounts of other substances mixed with the lime, and their variety is infinite.

30. True Cements.—When limestone ($CaCO_3$) contains clay, the process of calcination produces a compound which, due to the silica in the clay, gives the product the power of solidifying or "setting" when wet, either under water or in the open air. The degree of heat employed in the calcining process, and the relative proportions of clay and limestone, determine whether the product is hydraulic lime, quick-setting cement, or Portland cement. These cements were calcined formerly from deposits of the constituent materials just as they were found mixed in the earth, and the varieties of these mixtures were such that the resulting cements were not uniform, but the application of chemistry within recent years for the purpose of securing exactly the amount of each material required, and of avoiding deleterious materials, has brought about the extensive manufacture of a high grade of Portland cement. This has for most uses displaced other kinds of building cement, but has not displaced the use of lime for mortar, and there are cases in which a quicker setting cement may be more advantageously used than Portland cement. The name "Portland cement" comes from the supposed resemblance of the dry cement to Portland stone, in England, and was given it by its discoverer, in 1824.

31. Requisites in Selecting Raw Materials.—In any natural materials chosen for the manufacture of this cement, there must be ascertained:

(1) The proportions of the required ingredients contained.

(2) The kinds and quantities of other ingredients, which may be harmful in quantity or because of their chemical action.

32. Composition of Cement.—It is now established that the essential raw ingredients of Portland cement are limestone, 75 to 77%,

and alumina (Al_2O_3) and silica (SiO_2) 20 to 25%. The alumina and silica are commonly found combined as * clay, which is a silicate of aluminum ($Al_2O_3 2SiO_2$) + $2H_2O$. All cements contain other ingredients due to the essential materials not being pure in nature and from contact with fuel in calcination. Some of these accidental ingredients may improve the cement, others are inert and harmless except that they exist in such quantity as to displace essential ingredients, and others are positively harmful, if present in quantity, because of the chemical action they produce. There are accidental ingredients usually amounting to about 5%, but these must not include over 1.75% anhydrous sulphuric acid (SO_3), nor over 3% of magnesia (MgO).

Excess of clay causes a cement to "set" quickly, while excess of lime causes it to "set" slowly or imperfectly. Iron oxide gives cement its color. Portland cement is improved in dry storage, as any excess of lime particles are air slaked.

33. Manufacture of Portland Cement.—A cement manufacturing plant is usually located at or near a natural deposit of the materials composing cement. These materials may or may not be a natural mixture, but in either case chemical analyses must be made to determine, (1) the per cent of lime, (2) the per cent of clay, and (3) the per cent and kind of other ingredients. This analysis determines the fitness of the deposit for cement manufacture. With a cement plant established, the essential steps in manufacture are:

(1) Chemical analysis in the laboratory to determine the correct proportion of lime and of clay for making up a kiln charge.

(2) Grinding the properly proportioned ingredients to a very fine state, which also accomplishes their thorough mixture. These may be coarsely ground before mixing, but must be ground after mixing sufficient to pass through a sieve of about 900 meshes to the square inch. Lack of proper grinding may cause the cement to be worthless.

(3) Burning the ground materials to a state of incipient fusion, to change their chemical composition. This is done in a long, cylindrical kiln, built of iron plate, lined with refractory brick and

* The relative proportions of silica and alumina, as compared with the limestone in cement, are found by Messrs. Newberry from the formula Wt. of limestone = 2.8 × wt. of silica + 1.1 × wt. of alumina.

mounted to revolve on its axis at a slight inclination to the horizontal. The ground mixture is introduced wet or dry at the higher end, and the fuel oil, gas, or powdered coal, is blown in at the lower end where it ignites in a flame maintained by the continuous introduction of fuel. The finely divided cement material is gradually dehydrated and deprived of its carbon dioxide as it is tumbled by the slowly revolving kiln, presenting every part of the mass to the heat, and is finally vitrified at a white heat into small clinkers varying in size from that of a pea to that of a walnut. These clinkers are kept from fusing by being tumbled from the lower end of the kiln at the proper time. Their continuous falling from the kiln is due to the kiln's inclination and slow revolution.

(4) Grinding the clinker to a fine powder. This is done in two operations. The first grinding is done between millstones, or in a revolving cylinder containing steel balls about 6″ in diameter. The pulverizing is then accomplished by machines for the purpose, in one form of which the cement is fed into one end of a revolving cylinder partly filled with flint stones about as large as walnuts. The pulverized cement issues from the other end of the cylinder. It must be ground so fine that not more than 8% of its weight will fail to pass through a sieve of no. 100 mesh (100 x 100 meshes per square inch).

34. Uses of Portland Cement.—Cement mixed with water is virtually a plastic stone, and it can be used for many purposes in place of stone with economy in shaping to the form required, and advantage in securing a hard, fire-proof material. It may be used for shop floors, buildings, foundations for heavy machinery, bridge piers, walks, waterworks dams, reservoirs, walls, dry-docks, culverts, etc. A concrete casing will protect iron or timber structures from corrosion in air or in water, and will protect exposed iron work of structures from effects of conflagration.

Strengthened with iron bars, or meshed wire, placed in it when it is being moulded to shape, it is known as re-enforced concrete, and will thus form bridge floors, bridge spans, and the upper floors of buildings which must support great weight.

In marine use, concrete is limited because of its weight. It may be used as permanent ballast in the bilges of steel ships, and is an effective protection from corrosion when applied to absolutely clean

iron or to iron surfaces covered with closely adhering red rust. When so used, cement may be mixed with water and applied with a brush, or it may be mixed in the proportion of about two parts sand and one part cement and applied wet, with a trowel, in a layer varying from 1/4 inch to any thickness desired. In this way ships' tanks, bunkers, and bilges are protected, as the mixture forms a close bond with the iron. In no case will this bond form if the iron is oil coated.

35. Cement Mixtures.—Cement and water alone are known as "neat" cement, and are seldom so employed except where economy is not considered, or for purposes of maximum strength.

For most purposes a mixture of sand, broken stone, and cement gives ample strength, and is far more economical than the use of cement alone.

The following table of parts by volume, gives various concrete mixtures:

No.	Portland Cement.	Sharp Sand.	Broken Stone.	Uses.
1	1	2	4	Highest grade of miscellaneous work.
2	1	3	6	For largest building foundations.
3	1	4	8	For ordinary construction.
4	1	4	10	For economical construction.

In these mixtures, the broken stone merely fills space, and if not available, the proportions of cement and sand should remain as given.

The sand also fills space, saving cement, and for strength it is essential that enough cement be used *to surround entirely each grain of sand* and thus form a perfect bond between cement particles. Broken stone and sharp sand present corners and angles for the better attachment of cement, as claimed by some users, but beach sand, the grains of which have been washed round by the sea, and rounded pebbles, are also frequently used with cement.

36. Method of Using Concrete.—For shaping concrete to a form required, the usual practice is to make a form of planks or timbers, well braced, enclosing the space which the concrete is to occupy. The mixture is carefully made in a mixing machine or by men with

shovels, wet with clean water to a mushy consistency, deposited and tamped in place. Sea water has not an adverse effect on Portland cement of good quality. When once wet, the mixture must be promptly placed in the form, as it will "set" in an hour or less. After setting, the mass is at first very weak and may be crumbled by pressure of the hand, but if left undisturbed it gradually hardens to the consistency of stone, requiring months or years for reaching final limit of hardness. In setting and for a few hours afterward, the mixture must be kept wet. In extensive work, where a form cannot be filled in one day, the upper surface is left rough at the end of each day's work to give a suitable surface for the close bonding of the mixture deposited the following day.

When concrete is dumped into a form submerged in water, it is essential that the mixture be subjected to as little wash as possible for the fine particles of the different materials composing the cement must be thoroughly mixed, and these must form unbroken contact throughout the interstices of the sand and stone in order to insure a solid, well bonded mass after setting.

Concrete work is practically impervious to water, but not absolutely so in all cases.

37. Causes of Setting and Strengthening of Cement.—It is thought that the setting of cement is due to the crystallizing of the silicate and aluminate of lime, which, in their dry and anhydrous form after burning, are soluble in water, but which pass into the hydrated state when sufficiently wet, in which state they are insoluble.

The hardening after setting is due to a continued crystallization of salts from solution, accompanied by other chemical and physical changes which occur very slowly and which are not well understood.

38. Wood. Use as Parts of Machinery.—Very little wood is now used as engine or machinery parts. Metal has displaced wood almost entirely in moving and stationary parts of machines, and in many general uses for which wood was once exclusively employed. The present highly developed industry of pressing sheet metal to many forms more or less intricate has made it possible to substitute metal for wood in furniture, house and ship trimmings, automobile body fittings, utensils and many other articles.

However, wood remains a very useful structural material, and is particularly of value in engineering needs as a material for making patterns of objects to be cast in metal, as will be seen in Chapter VIII.

Wood is used for decks and sheathing of ships, and for many parts in ship equipment. About the only important use remaining for it in marine machinery is as bearings for propeller shafting. These bearings support that part of the shafting between the propeller and the body of the ship. They cannot be given care or attention except when the vessel is in dry dock, and are lubricated entirely by the water in which the vessel floats. Lignum vitae, a tropical wood, is used for this purpose.

39. Lumber and Timbers.—Wood for general uses is handled commercially in the form of lumber or timbers. Trees are felled, and

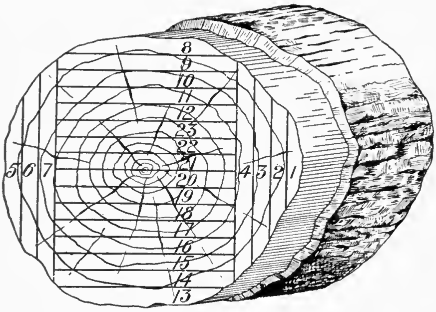


FIG. 2.

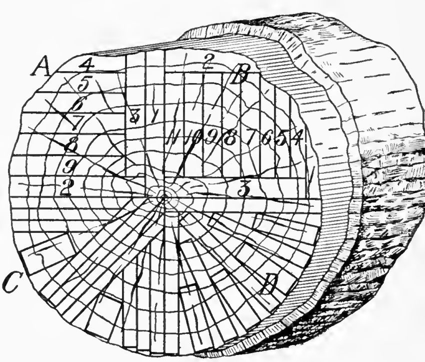


FIG. 3.

that part of the lower trunk free of large limbs is sawed into logs usually a few inches longer than an even number of feet. These logs are hauled to the sawmill and sawed into widths and thicknesses as required.

The log end in Fig. 2 is numbered to show the consecutive cuts in the usual method of sawing. Most of these are tangential cuts, *i. e.,* more nearly perpendicular than parallel to the radius of the log end. Pieces 20 and 21 are known as quarter-sawed pieces, as their width is cut along the radius of the log end. Tangential cuts are cheaper because of less handling on the saw carriage and less

waste of the log material, but lumber from these cuts warps more, is less durable, and does not show the fineness of grain when compared with quarter-sawed lumber. The upper half of Fig. 3 shows a method of getting more quarter-sawed cuts from a log than are obtained in Fig. 2 without greatly increasing the cost of cutting. The log is quartered and each quarter is sawed into pieces as consecutively numbered, quadrant A giving two quarter-sawed pieces, 1 and 2, and two pieces, 3 and 9, which are nearly quarter sawed. Quadrant B shows another method of sawing, giving pieces 3 and 11, quarter sawed, and but one piece, No. 10, corresponding to pieces Nos. 3 and 9 of quadrant A. True quarter sawing is shown in quadrant D, and approximate quarter sawing, with less waste, is shown in quadrant C, of Fig. 3.

40. Lumber Grading.—The several pieces sawed from a log are not of the same quality, but vary more or less in grade. The slabs, covered on one side with bark, and the culls or very unsound pieces, are of no value as lumber. The ungraded lumber from a log is known as *log run.* In large mills, log run is graded as to quality after it is finally sent from the saw on roller conveyors and the several grades are stacked separately in such a way as to allow ready access of air for seasoning and to shed rain. After drying, and when removing it from the stacks for shipping, the lumber is further subject to an adopted form of inspection, in which each piece is graded for the purchaser's acceptance.

41. Hard and Soft Wood Lumber.—Hard woods are those cut from the broad-leaf trees (as oak, hickory, poplar), and soft woods are those from the conifers, or needle-leaf trees (as pine, cedar, fir and redwood).

42. Heart and Sap Wood.—The wood surrounding the center of a tree is heart wood and outside of this is the sap wood, usually lighter in color than the heart. Sap wood, except in certain trees, as ash and hickory, is less hard and durable than heart wood. However when the heart wood at the center of the tree is exposed in the surface of a board, it tends to split away from the board. The amount of sap or heart wood in a piece of sawed timber may be seen by the difference in color of the sawed surface, also end inspection will show from which part of the tree the piece is taken.

In Fig. 4 the large radii of curvature of the rings show these as sap pieces, the points A being nearest the bark. Fig. 5 shows

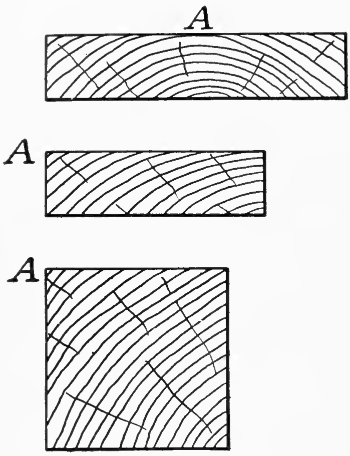


FIG. 4.

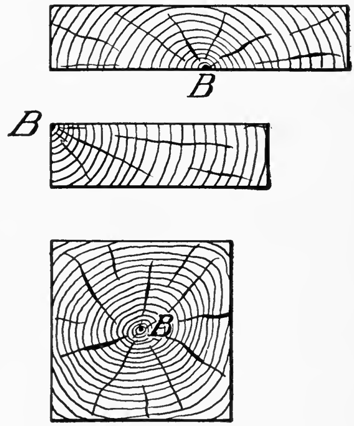


FIG. 5.

heart pieces, indicated by the curvature of the rings. The heart of the tree is at B.

43. Lumber Inspection Rules.—For uniformity in lumber sizes and qualities, certain general rules are adopted by lumber producers, who adopt, also, specific rules for the inspection of each kind of wood according to its uses. Lumber rules are subject to changes particularly because of the increasing scarcity of wood.

(1) Standard lumber lengths are 6, 8, 10, 12, 14, and 16 feet, though 6- and 8-foot lengths are for special uses. Boards measuring an odd number of feet are classed with the next lower even lengths, unless specified otherwise.

(2) Standard thicknesses are 3/8, 1/2, 5/8, 3/4, 1, 1 1/4, 1 1/2, 2, 2 1/2, 3, and 4 inches. Pieces larger than 4 x 4 inches are called timbers.

(3) The standard qualities or grades for hardwoods are, usually, firsts, seconds, and one or more grades of common. Soft woods are graded according to their uses. An inspector determines the grade to which any piece of lumber belongs by its width, amount of heart or sap, and defects affecting its strength and appearance.

(4) Inspection is usually made of the worst side of the board, and warps are always considered as defects.

It is not uncommon for purchasers of large amounts of lumber to have their own specifications for the general inspection of lumber.

44. Standard Defects.—An example of the standardization of lumber defects is given by the following copy of Navy Department General Lumber Specifications. Each one of the following items constitutes a standard defect:

(*a*) One sound knot, 1¼ inches in diameter, called a standard knot.

(*b*) Two knots not exceeding in extent or damage one standard knot.

(*c*) Wormholes, grub holes, or rafting-pin holes not exceeding in extent or damage one standard knot.

(*d*) Heart centers, shakes, rot, or dote not exceeding in extent or damage one standard knot.

(*e*) Splits which do not exceed 12 inches in length in firsts, nor one-sixth the length of the piece in seconds. Not more than 25 per cent of the whole number of pieces in each grade may be so split.

NOTE.—Wide pieces of lumber that would take two or three standard knots may have, if properly located, one large knot, equal to two or three standard knots, if there are no other defects.

Shakes are splits in the end of a board due to seasoning, generally occurring before the board is cut from the log.

Checks are cracks showing in the surface of a board, due to seasoning, and are sometimes large enough to be defects.

Dote is unsoundness due to decay.

Wane is the beveled or bark-covered edge of a board.

45. Rough and Dressed Lumber.—All lumber direct from the saw is rough lumber. After seasoning, the better grades may be re-sawed into smaller pieces and are frequently planed smooth, on one or both faces and one or both edges, by machinery, before marketing. Lumber thus planed is said to be dressed, and is sold at the width and thickness it had when rough. Examples of designations of dressed lumber are as follows: S1S means surfaced (or dressed) on one side; S1S1E means surfaced on one side and one edge; S2S2E means surfaced on both sides and both edges.

46. Lumber Measurement.—Lumber and timbers are measured and sold by board feet. A board foot has a surface 12 x 12 inches and a thickness of one inch. Boards less than an inch in thickness are regarded as an inch thick in selling, but those of any fraction over an inch are sold for what they actually contain.

A specimen bill of lumber is as follows:

(1) 40 p. $2 \times 6 \times 16$
(2) 12 p. $\frac{1}{2} \times 8 \times 12$
(3) 80 p. $1\frac{1}{2} \times 6 \times 16$
(4) 30 p. $1 \times 12 \times 14$

Written in full, the first item, for example, reads 40 pieces 2 inches thick, 6 inches wide, 16 feet long.

The board feet in the 2d and 3d items are as follows:

In item (2), each piece is regarded as having a thickness of one inch. The surface of one piece in square feet is $\frac{8}{12} \times 12$; hence the item has a total of $\frac{12 \times 1 \times 8 \times 12}{12} = 96$ board ft.

In item (3), the surface of each piece is $\frac{6}{12} \times 16$ sq. ft., hence the item has a total of $80 \times \frac{3}{2} \times \frac{6}{12} \times 16 = 960$ board ft.

47. Durability of Wood.—Wood may be preserved indefinitely if kept dry or submerged in still water, and free from attacks of insects. Wood exposed to the atmosphere absorbs more or less moisture. Alternate wetting and drying, very common with posts or poles where they enter the ground, is an active means of decay. The best preserved wood is that buried in wet or damp earth, excluded from air and insects. Timbers preserved in this way have remained sound for centuries.

CHAPTER II.

A GENERAL OUTLINE OF METAL-PRODUCING PROCESSES.

48. Ores.—The common metals, excepting copper, do not occur free in nature, but are produced from their ores which generally require chemical treatment at high heat in furnaces. Uncombined copper, known as "native" copper, mixed with more or less earthy material, is found in some parts of the world, notably in the Lake Superior region, but the main source of all engineering metals is their ores, which are more or less abundantly distributed over the earth.

An *ore* is a natural substance composed of a metal chemically combined with one or more non-metallic substances. Ores of different metals are sometimes found incorporated in the same mass, and almost all ores are found mixed with impurities of a non-metallic nature, as rock, sand, clay, etc., known in mining as *gangue*. Many ore deposits within range of easy transportation cannot be profitably worked either because of excessive gangue or because of chemical composition of ore or gangue which renders smelting unprofitable.

49. Elimination of Gangue.—As an ore comes from the mine it is desirable to eliminate at once the gangue. This may be done more or less successfully with some ores by simple hand-picking methods, while other ores must be crushed in a stone breaker or stamp mill, and the gangue eliminated from the finely crushed mass by *dressing,* which consists of passing running water over the mass in a succession of boxes so that the current will carry the lighter particles to the lower boxes while the heavier particles settle in the upper boxes. There are ores from which the gangue cannot be removed except in furnace processes, and some ores have too little gangue to need preliminary separation.

Some ores are subjected to *weathering.* They are heaped in the open air and left exposed to sun and rain for weeks or months.

This disintegrates the lumps and washes away soluble salts and much powdered gangue.

50. Calcination.—Another method of reducing the quantity of impurity before the ore is transported from the mine is by calcination, which consists of heating the ores to a point short of fusion. This drives away moisture and some combined sulphur, and breaks up carbonates, changing them to oxides by driving off CO_2. Calcination is done crudely by making alternate layers of fuel and ore on the ground and lighting the fuel, but more effective methods are to confine the ore and fuel by walls, or still better by kilns, in which the heat is more intense and more uniformly distributed.

After calcining, the ore is ready for transportation to the smelter, which is usually located away from the mines for the convenience of obtaining fuel and labor.

51. Breaking up the Ore Compound.—The actual metallurgical operation of breaking up the chemical combination of metal with oxygen and with other elements in ores is done by heat in furnaces and is called the *dry process;* or is done by making a solution of the metallic compounds and breaking up these by chemical re-agents, known as the *wet process* or *leaching.*

Smelting, as used in the dry process, is the operation of fusing ores by heat in suitable furnaces. This is an essential step of metal extracting, and its meaning is usually broadened to include all steps of the process of heat extraction of metals.

Reduction is the separation of a metal from its oxide, though usually applied to the separation of a metal from any ore, whether oxide or not.

Roasting is the heating with free access of air in order to change the ore partly or entirely to an oxide for reduction later on.

The processes of extracting most of the common metals from their ores are complicated because of the several chemical changes necessary to extract the metal in a sufficiently pure state for use. The different chemical compositions of ores, their various grades due to the relative per cents of metal and of other ingredients contained, and the existence frequently of two or more metals in the same ore mixture, make the treatment of most ores very varied and

complex. By far the greater quantity of metals is produced by the dry process, and iron is very easily produced because its oxide ores are abundant and are smelted by the single process of reduction.

The treatment of ores of copper, zinc, lead, tin, nickel and antimony is more difficult. The object of each step in the processes of extracting a metal from its ores is to simplify the ore compound. This is done, as has been outlined in part, by (1) separating the ore from the gangue (par. 49), (2) driving away certain ingredients by a heat short of fusion (par. 50), and (3) fusing the ore one or more times in the presence of certain re-agents called fluxes which combine with the non-metallic substances and allow the liberated metal to separate and settle in an impure state. A metal thus obtained in the impure state must be refined before it is used.

52. Smelting Furnaces.—The step of the process named in item (3) of the preceding paragraph is that of smelting, and is usually carried on in furnaces built of common silica brick for the outer layers, and high grade refractory brick for the inner layers. This brick work is either incased in a shell of iron plates, or is held together by iron bands and rods, which are wholly on the outside of the furnace and do not enter the fire space. There are several modifications of furnaces for smelting ores of different metals, but all smelting furnaces are included in the two general types of this class, namely, the *blast furnace* and the *reverberatory furnace.* These must be strongly built on permanent foundations, and must be able to stand the intense heat of the operation.

53. The Blast Furnace.—Fig. 6 shows the essential parts of a blast furnace for smelting iron. It is given the name of blast furnace because combustion is maintained by forcing a blast of air through the mass of fuel, ore and flux which completely fills the furnace. This type of furnace is vertical so that gravity may assist in disposing of the fused products. The main point of difference from the reverberatory furnace is that ore and fuel are mixed in the blast furnace and are kept separate in the reverberatory furnace.

Figs. 6a and 6b are two views of the outside of a blast furnace. They are lettered to agree with the description given for Fig. 6.

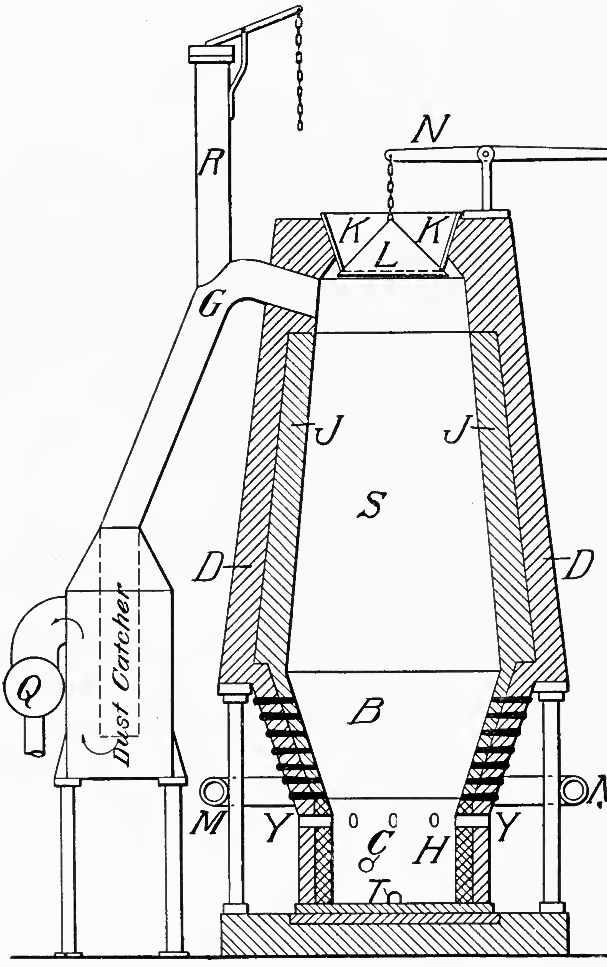


FIG. 6.—Blast Furnace.

The parts of this furnace, shown in Fig. 6, are designated as follows, viz.:

S. Shaft. This extends from the top down to the part of largest diameter.

B. Boshes. This is the tapered portion below the shaft. Built in with the brick work of the boshes are many hollow wedge-shaped segments of copper. These segments are placed with alternate segments of bricks to encircle the boshes, and many layers of this construction make up the walls of the boshes. These copper segments are known as "bosh plates." Some of them are marked *P* in Fig. 6a. Water is circulated through each bosh plate, by a system of external piping, to allay the intense heat at that part of the furnace and thus prevent injury to the bosh walls. The bosh plate edges do not extend in quite so far as does the brick work, and are protected by a covering of clay. If a plate becomes clogged by sediment from the circulating water, or if its inner edge is melted or damaged, it can be pulled out and replaced by a new plate by reducing the blast pressure while this work is in progress.

Y. Tuyere holes. These openings conduct into the furnace the air of the blast. Fig. 6 has eight tuyere holes. The tuyeres are metal tubes leading from the blast main into the furnace through the tuyere holes. Tuyeres are not shown in Fig. 6, and the horizontal portion (or tuyere proper) is disconnected and removed in Fig. 6a. Each tuyere is surrounded by a helix of pipe through which water circulates to keep the end of the tuyere from melting in the furnace. Fig. 6a shows at *E* an opening, covered by a mica door when the furnace is in use, which enables the furnace man to see the interior of the furnace through the tuyere when in blast.

M. Hot blast main. This is a pipe 3 ft. or more in diameter, made of iron plates and lined inside with refractory brick. It encircles the furnace, delivering highly heated air from the blast stove to the tuyeres.

H. Hearth. This is the part of the furnace below the line of tuyere holes which receives molten slag and metal, and when the slag, which floats on the metal, reaches the height of the cinder notch *C*, it is drawn off.

T. Tapping hole. Metal is tapped from the hearth through this hole. In tapping, an iron bar is used to dig out the clay plug stopping the hole, and when the metal has run out, another plug is forced in to stop the hole, by means of the ram *U* (known as the "mud gun") swung from the small crane *W*.

G. Gas main or "down comer," a brick-lined pipe leading away the gaseous products of the blast and delivering them, through the dust catcher, to the gas main, *Q,* which distributes them to the blast stoves.

J. Shaft lining. This lining is of highest quality refractory brick (fire clay) laid in a mortar of fire clay. The lining can be renewed when worn out. The double hatched lining below the tuyere holes in Fig. 6 is not subject to excessive wear.

D. Silica brick body, in Fig. 6. The furnace body is encased in plate steel marked *D* in Fig. 6b.

K. Cone. This is a cone-shaped hollow cast iron ring built into the top or "throat" of the furnace.

L. Bell, a cast iron cone suspended by a heavy chain from the lever *N.* This cone closes the throat of the furnace and is opened for admitting materials of the furnace charge.

R. Stand pipe. Before lowering the bell to admit a new charge to the furnace, the lid of the stand pipe is raised to relieve the gas pressure at the top of the furnace. This obviates the escape of gas and flame from the furnace throat.

54. Blast Furnace Modifications.—The principle of the blast furnace as shown in Fig. 6 is applied to the smelting of copper and lead ores, but the furnaces used for these ores are somewhat modified. Iron smelting furnaces vary from 50 to 100 ft. in height, but copper and lead furnaces are much smaller and are not always circular in cross section. In copper and lead furnaces the boshes and at least part of the shaft have merely inner and outer surfaces of iron, with water circulating between them. This water jacket arrangement is necessary as the oxides of these metals attack a fire brick lining. The cooling effect of the water is such that the inner surface of the iron jacket becomes covered with a solidified slag which is replaced as fast as it wears away.

The modifications of this furnace for lead and copper smelting are due to the differences of the ores of these metals from the ores of iron, and to the complexity in smelting these as compared with iron smelting.

55. Acid and Basic Ores.—The earthy matter of ores consists mostly of silica (sand), silicate of aluminum (clay), limestone, and magnesia. All of these are seldom found in the same ore, but

almost all ores contain (1) silica and silicate of aluminum, or (2) limestone and magnesia. The ores containing a predominance of the materials of group (1) are *acid* ores, and those containing a predominance of the materials of group (2) are *basic* ores. Acid ores are in much greater abundance than basic ores.

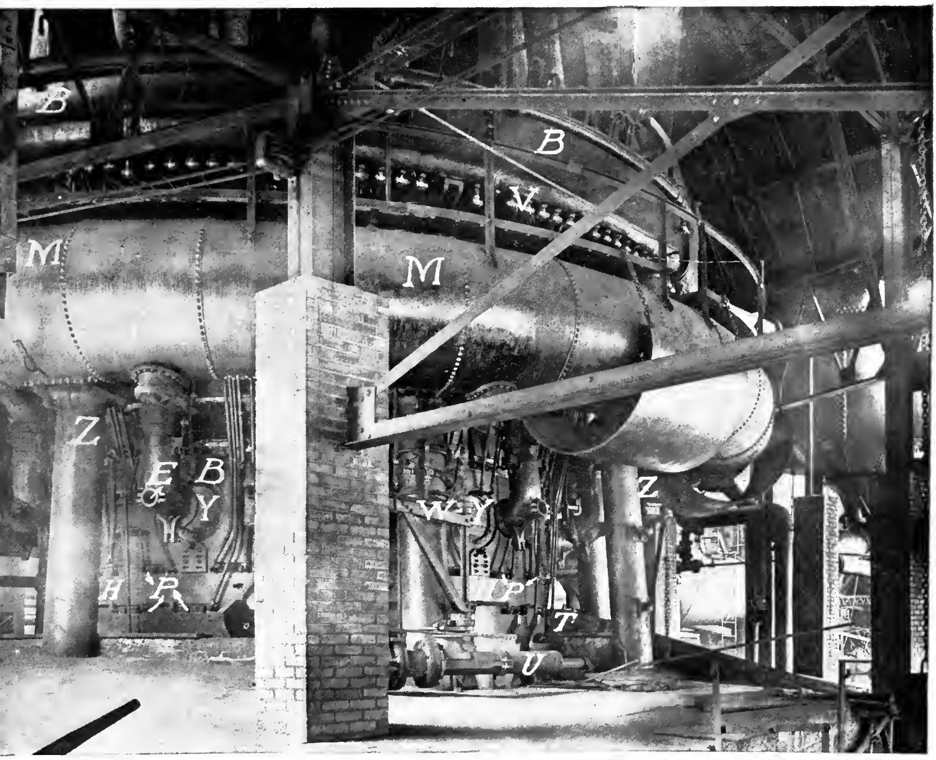


Fig. 6a.—Base of a Blast Furnace.

B—Boshes.
E—Peep hole.
H—Hearth.
M—Blast main.
P—Bosh plates.
T—Tapping hole.
U—Mud gun.
V—Water valves for bosh plates.
W—Mud gun crane.
Y—Tuyere holes.
Z—Furnace supports.

56. Fluxes.—The usual operations of smelting require that an ore shall always be mixed with a flux. The ore is either acid or basic, and the flux must be either basic or acid, opposite to the character of the ore. At the temperature of the furnace, neither the acid

nor the basic substance in an ore will melt, and in order to melt and dispose of it, there must be introduced with the ore a certain amount of flux, which combines chemically with the earthy substances of the ore, forming *slag*. At the temperature of the furnace the slag is molten, and when slag and metal collect in the hearth, the slag floats on the metal and protects it from oxidation.

The materials used as fluxes in smelting are (1) silica and silicate of aluminum as acid fluxes, and (2) limestone and magnesite (an impure magnesia) as basic fluxes. These fluxes are the same materials as those found with ores which determine their acid or basic character, hence it is necessary to place with an ore the flux opposite in character to that which the ore is found naturally to contain.

In making up a furnace charge, the chemical composition of the ore must be determined in the laboratory, and a flux must be chosen, in kind and quantity, which will unite completely with the earthy materials of the ore. Too little flux will not take up all the refuse parts of the ore, and too much will act in disintegrating the fire brick lining of a furnace in spots not protected by a slag coating. A practical smelter can judge from the color of a broken piece of cold slag whether or not the flux is in sufficient quantity, and an occasional analysis of the slag is a beneficial check. Sulphur and phosphorus must be avoided in fluxes, and are not desirable in ores.

57. Blast Furnace Operation.—This description applies particularly to iron smelting, but it is also the essential part of blast furnace operation for smelting other ores. The starting of a blast furnace in operation is called "blowing in." A light fire is started in the hearth and is for a while supplied only with enough fuel to keep it going. Care must be taken to heat up and dry out the furnace very slowly to avoid cracks in the newly built or repaired parts, or in the slag coating which acts as a protection to the furnace walls. Very gradually the quantity of fuel is increased and when it is above the tuyeres, a light blast is started to increase combustion. After a few weeks, with a large iron smelting furnace, the shaft becomes well filled with fuel and the heat has reached a maximum.

A little slag from the slag dump is now added. This melts and runs down, covering the bottom of the hearth and keeping it hot,

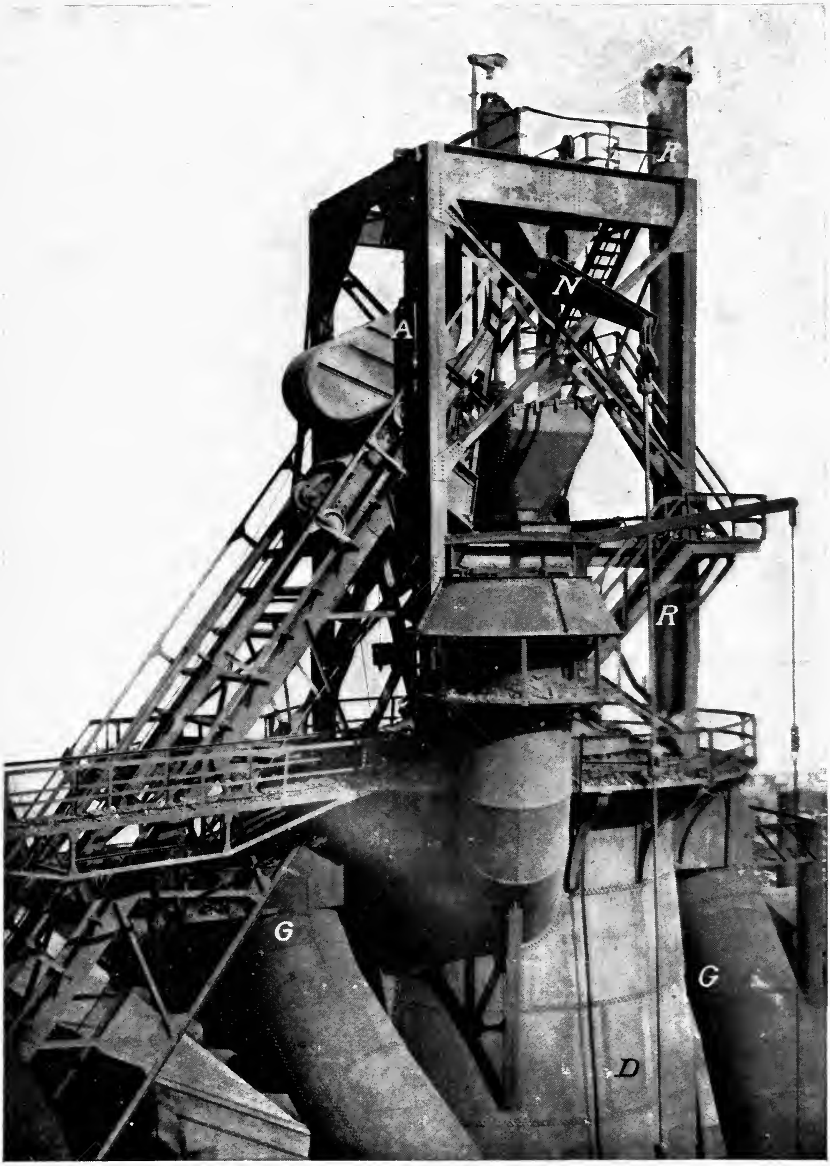


Fig. 6b.—Top of a Blast Furnace.

A—Charging car.
D—Furnace shaft casing.
G—Down comer.
N—Bell lever.
R—Stand pipe.

The tap hole is stopped with clay. Ore and flux are added, the blast pressure is increased to that desired, and the furnace soon reaches a condition of maximum output. The furnace may be kept in operation for months without cessation, until it must be stopped for relining or repairs. When in operation, the furnace is charged at intervals of a few minutes with a layer of coke and then a layer of flux and ore. The material is sprayed with water, hoisted to the

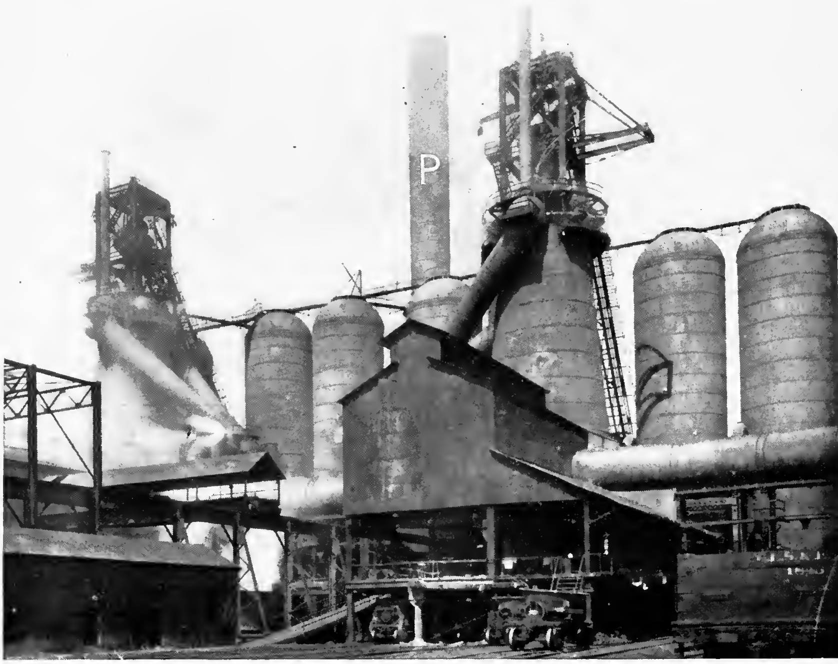


FIG. 7.—Blast Furnaces and their Hot Blast Stoves.

top of the furnace, and dumped into the cone. The water prevents the carrying of an excessive amount of dust from the furnace into the "down comer." In Fig. 6b, the charging car *A* has just reached the top of its track and is about to be automatically dumped into the hopper over the cone.

The air blast is supplied by a centrifugal or other form of blower, and is forced through coils of heated pipe for lead and copper, or through a large stove (called a regenerative or hot-blast stove) for

iron, entering the furnace at a high heat through the hot-blast main and tuyeres. The most intense heat of the furnace begins immediately above the tuyeres and extends up as far as the oxygen lasts for the complete burning of the fuel. This is called the *fusion zone.*

The ore heated above the fusion zone disintegrates, is reduced, giving up its gangue to the action of the flux, and as it sinks into the zone of fusion, it gradually melts. The metal, more or less impure, trickles to the hearth, and the slag also runs down, floating on top of the metal. When the slag rises to the level of the cinder-notch it runs out, and the metal is tapped out before it is high enough to reach the cinder notch. Care is always taken to leave a covering of slag over the metal. The slag, drawn off at the rear or side of the furnace, is conveyed along a trough or trench into cars with sheet steel bodies, and is hauled away and dumped when cool. Slag of some compositions is now used for making Portland cement. The metal is tapped several times during each day, and is conducted from the furnace along a trench in the floor. This trench is lined with a mixture of sand and clay which is baked hard to prevent wearing away by the erosive action of the metal. Fig. 16 shows metal pouring from a furnace, and Fig. 17 shows the ladles on cars to receive it.

When a furnace is to be shut down, or "blown out," the ore charge is gradually reduced and stopped. Flux and fuel are continued until all metal and slag are tapped out, and the flux is then discontinued. The fuel is gradually reduced, the blast pressure is lowered and finally shut off, and the fire slowly burns out. The furnace must be allowed to cool gradually before being emptied.

58. The Blast Stove.—In blast furnace smelting of copper and lead, the gases passing from the top of the furnace do not contain much gas which will burn, hence they are allowed to escape, but in the iron smelting furnace not enough oxygen reaches the upper part of the furnace to unite with all the incandescent carbon of the fuel. As a result of this, much CO_2 is reduced to CO, which passes from the furnace unburned. To let this gas escape into the atmosphere would be a considerable loss of fuel, hence it is conveyed through the "down-comer" and dust catcher to a large stove called the blast or regenerative stove, where it is burned to heat the

brickwork of the stove. After the brickwork has become very hot, the gas is shut off from this stove, and air is blown through to absorb the heat on its way to the blast furnace through the tuyeres.

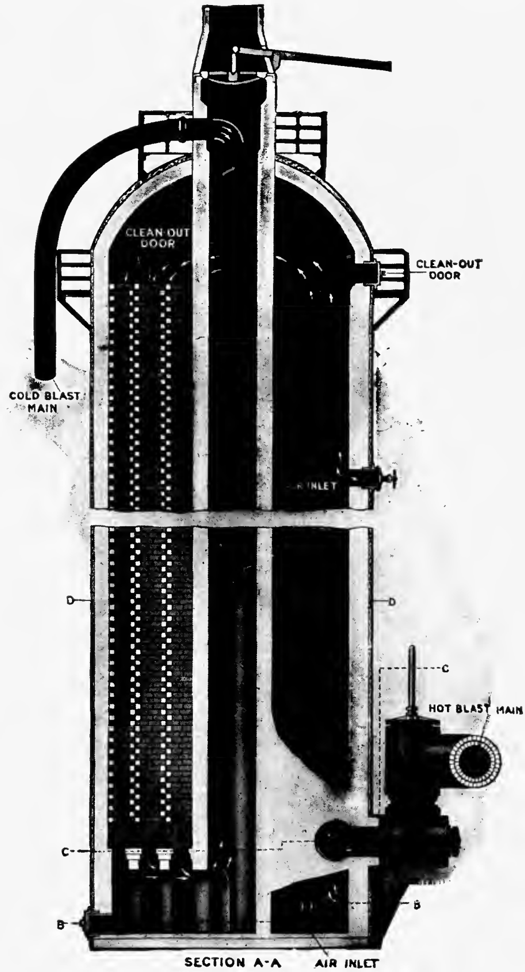


FIG. 8.—Hot Blast Stove (Vertical Section).

In this way the blast is supplied with air at about 1400° F., and the intensity of the furnace heat is much greater in the fusion zone than if cold air were blown in.

Fig. 8 shows a form of blast stove used for this purpose, known

as the Calder Stove. Several other forms of stoves are used, all operated on the same principle and differing only in interior arrangement. Fig. 7 shows a group of five stoves which are con-

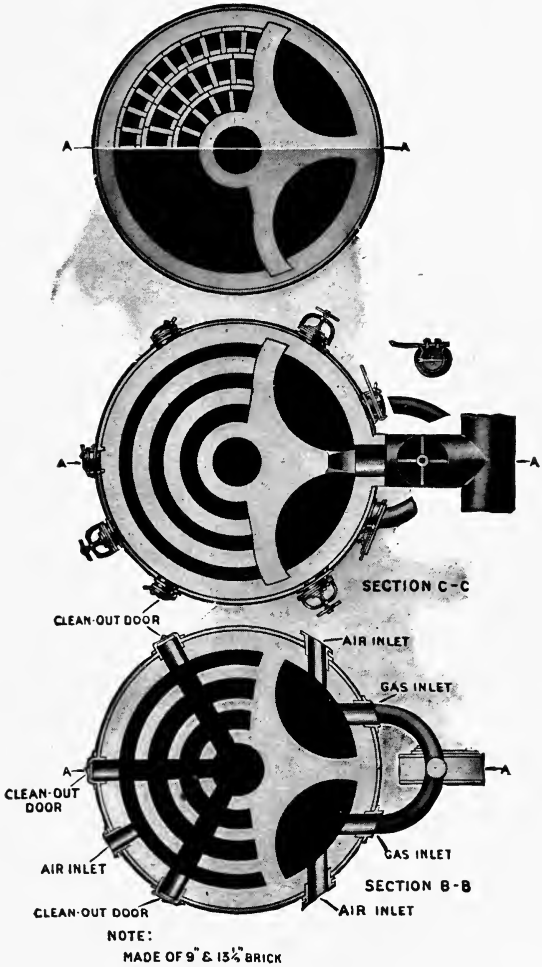


FIG. 8A.—Hot Blast Stove (Horizontal Sections).

nected to their common chimney P by an underground smoke conduit. The stoves are made of an outside casing of steel plates and an interior lining of refractory brick. Brick partitions are so placed as to check the passage of air and gases.

The stove in Fig. 8 is operated as follows: Valves connecting the interior space of the stove with the hot and cold blast mains having been closed, the chimney damper is opened and gas from the dust catcher is admitted to the stove through the gas inlet marked in section *B-B*, of Fig. 8a. This gas is hot enough to burn just as soon as air is admitted through the various air inlets, which are regulated by dampers. Combustion takes place in the two large vertical spaces in the right half of the stove, the burned gases are drawn downward by the chimney draft through the small vertical spaces into which the left hand part of the stove is divided, and, following the small arrows, enter the circular conduit through openings at the bottom of the stove. In passing downward, the gases give up much heat to the brick partitions, and finally they escape through the chimney which surmounts the stove. After about an hour of this operation, the brickwork has reached its maximum heat. The gas from the dust catcher is then shut off, the chimney damper is closed, the valves connecting the stove to the cold and hot blast mains are opened, and atmospheric air is forced by blowers through the stove in a direction opposite to that taken by the gases which were burned to heat the brickwork. This part of the operation continues for a half hour or more, during which the air is delivered very hot to the hot blast main. The operation is again reversed as soon as the brickwork begins to become appreciably cooled.

At least two stoves, and usually four, are installed for each blast furnace, so that at least one stove may be constantly in use for each part of the reverse operation just described.

59. Reverberatory Furnaces.—Two types of the reverberatory furnace are used in smelting. Fig. 9 shows a *roasting* furnace in which ores are roasted to simplify them before they are placed in the *melting* furnace shown in Fig. 10. The melting furnace is much used for smelting copper and tin ores, for refining copper and tin, and for melting copper and brass in large quantities in the foundry for castings.

Both furnaces have several similar parts, as follows:

G. Grate for fuel. *D*. Fuel door.

A. Ash pit.

W. Bridge wall to separate the fuel from the ore or metal in the furnace.

B. Furnace arch, which reflects heat down upon the furnace charge.

F. Hearth, on which the charge rests.

C. Chimney opening, controlled by a damper.

These furnace roofs are arched from side to side, and the sides are braced by iron plates connected with long rods over and under the brickwork of the furnace. The melting furnace must generate

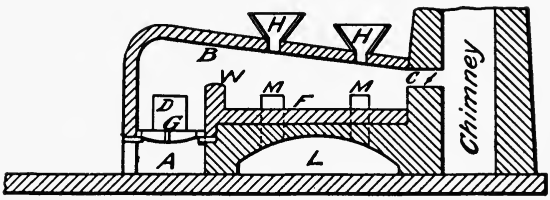


FIG. 9.—Reverberatory Furnace for Roasting.

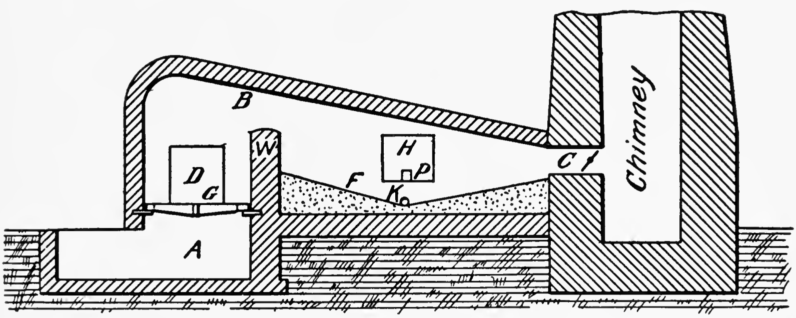


FIG. 10.—Reverberatory Furnace for Melting.

a more intense heat than the other, hence its fire box is larger. These furnaces have no air blast, and their draft is produced by a tall chimney. The fuel is usually oil, gas, or soft coal which produces a long flame.

The roasting furnace has a flat hearth over which the ore, introduced through covered hoppers *H*, is evenly spread. The hearth is so shaped that every part of it can be reached by a rake or rabble through one of the doors *M* (two on each side) and when roasting has reached the proper degree, a plate in the hearth at the edge of

each door is lifted and the charge raked into the arched space *L*. From there it is taken to the melting furnace.

In the regular process of smelting, the slope of the bottom leads the metal to the breast *K* (Fig. 10) from which it is tapped. This opening is stopped with a clay plug which is dug out by a pointed iron bar when the metal is to be drawn off. The slag is removed through an opening at the back of the furnace, higher than the breast opening.

After charging the furnace with ore and flux, the door *H* is plastered around the edges with clay to exclude air. The progress of the operation is watched and any stirring needed is done through the small covered opening *P*.

Unlike the blast furnace, the melting reverberatory furnace can be placed in operation and cooled down in a short time. Usually only a single charge is smelted and drawn off, after which the furnace is opened, recharged, and again put in operation without much lessening of temperature. Feeding hoppers may be placed on top and the furnace made to operate continuously.

60. Atmosphere of Reverberatory Furnaces.—These furnaces may be so fired and the air supply to the fire so regulated as to make the furnace action oxidizing or reducing. Oxidation demands (1) an excess of air beyond that needed for complete oxidation of every combustible part of the fuel and (2) that the excess air be at the required heat to combine with (burn) the material to be oxidized.

Reduction demands (1) that the supply of air be deficient for the complete burning of the fuel and (2) that the unburned gases from the fuel be kept at or above their igniting temperature, in which case they will extract oxygen from oxides in the charge having a less affinity for oxygen. An oxidizing atmosphere necessitates a thin fire and a full supply of air over and under the fuel, while a reducing atmosphere necessitates a thick fire with small air supply, particularly above the fuel. In both operations it is imperative that the fire shall burn vigorously enough to maintain the degree of heat required. Reverberatory furnaces are not economical in fuel.

61. Refractory Materials.—An important feature demanding particular attention in all furnaces is the interior lining, because of the intense heat and the chemical action to which furnace linings are subjected. A lining must (1) resist oxidation and reduction,

(2) must not melt nor disintegrate from heat, (3) must reasonably stand the mechanical wear of the furnace charge, and (4) must not, unless so intended, enter into chemical combination with the furnace charge. Crucibles, in which metal is melted, the linings of ladles for receiving and pouring molten metals, and the linings of all classes of heating furnaces must fulfill substantially the same requirements.

The refractory materials commonly used in all branches of smelting, refining and melting of metals, including the processes of steel making, and in heating furnaces, are

(1) Silica (common sand), SiO_2.
(2) Silicate of Aluminum (clay), $Al_2O_32SiO_22H_2O$.
(3) Magnesite (magnesia), MgO.
(4) Chromite (chromium oxide), Cr_2O_3FeO.
(5) Dolomite (magnesian limestone).
(6) Bauxite (alumina), Al_2O_3.

All of these substances are more or less impure as found in nature, containing iron oxide, sand and clay, and in some cases, soda, potash, and organic matter. Practice has established the limit of impurities not detrimental to the uses of these materials for specific purposes.

Silica and clay are closely associated in use as refractory materials. They are used far more than the other substances named, and are adapted for use in many kinds of furnaces. A mixture of the two materials is known as *fire clay,* and different proportions of the mixtures are employed in different furnaces, according to results obtained by experience. Silica resists the action of heat and alumina resists the action of metallic oxides. Silica is not plastic when wet and must be mixed with enough clay to make the grains stick together. *Ganister* is a natural rock composed of silica and clay in the proportion for making high-grade fire brick.

Silica is an "acid" material and cannot be used for bottoms of furnaces for basic steel making, and for linings of other furnace bottoms requiring basic material. For these uses, magnesite and chromite are used in brick form, and dolomite is used for patching, but it is more or less objectionable because of its lime content, an excessive amount of which causes disintegration at high temperatures. Chromite is a neutral material, that is, it is neither acid,

basic, oxidizing nor reducing in its chemical action, and is unexcelled for use where a material is needed to resist high heat and chemical action.

Bauxite is exceedingly refractory and is neutral, but has very limited use because it is subject to excessive shrinkage and loses plasticity when highly heated.

Refractory materials are much used in the form of fire bricks. There are many standard commercial shapes of fire bricks, and many grades also, according to the purity of materials, skill in shaping and care in burning. The selected materials are thoroughly calcined, ground, well mixed in correct proportions with water, moulded to shape, dried in the open air, and slowly burned in a kiln which must be heated to a white heat and gradually allowed to cool. About 1 per cent of lime in silica bricks is necessary to fuse the particles together when burned. All bricks should be true to shape, and their surfaces must allow them to lie in close contact when placed for use. Each grade of bricks must be laid in a cement or mortar of like material ground fine. This cement fills spaces between the bricks, uniting the whole in a compact mass.

A good fire brick when broken should not show a crumbly mass of ingredients, with large grains of material loose and ready to fall out, but the mass should be dense, strong and thoroughly fused together.

62. Sources of Copper.—The greater part of the world's supply of copper is produced by smelting the sulphide ores. A very extensive source of supply of native copper is the Lake Superior deposit. Only a small supply of copper comes from oxides, carbonates and low-grade ores.

The sulphides and other ores, including those containing as little as 5 or 6% of copper, are smelted; native copper is melted down to separate it from rock and other earthy substances it holds; and very low-grade ores are leached by the wet process.

63. Producing Copper from its Sulphides.—In the smelting process, which is preceded by roasting the ores to remove some of the sulphur, large lump ores not too complicated with gangue and other metals, are smelted in the blast furnace, while the powdered ores and those of complex composition are smelted in the reverberatory furnace.

The process of producing copper is not direct and simple, as is the case with iron, but consists of a number of treatments under separate heats, or in separate furnaces and receptacles. The object of the several steps of the process is to simplify the copper compounds into a nearly pure sulphide by removal of other parts of the ore, principally iron and an excess of sulphur, and then to break up the copper sulphide and remove its sulphur by oxidation, leaving a somewhat impure metallic copper which is then refined.

Roasting the ore removes some of the sulphur and incidentally oxidizes some of the free copper and iron. The roasted ore is then

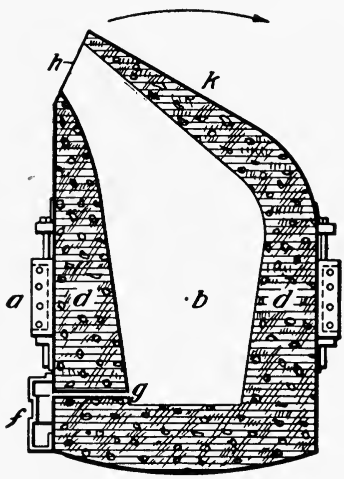


Fig. 11.—Copper Converter.

melted in a smelting furnace to convert the earthy matter into slag by use of flux, as in iron smelting, and the remaining product is a nearly pure sulphide of copper in which some iron sulphide remains. This product, known as "matte" or "coarse metal," is run in a molten state from the smelting furnace into a large refractory lined vessel called a converter, and cold air is blown through the molten mass to oxidize the sulphur and the iron.

Fig. 11 shows a cross-section of a converter. It consists of a shell *k* of steel plates with a lining *dd* of silica. The trunnion band *aa* supports the converter and allows it to be tilted about an axis *b* perpendicular to the plane of the page. The wind box *f* extends

part way around the bottom. It receives air through one of the trunnions, which is hollow and connected to a blower. The air is forced through several openings, as at *g*, into the molten charge. It combines with the sulphur, forming sulphur dioxide which escapes at *h* into the open air. The iron in the charge is also oxidized, this oxide forming a slag with the silica lining of the converter. The oxidation of sulphur and iron supplies heat which keeps the charge molten, and the blow is continued until the flame from the converter mouth shows that these are about burned out and that copper is beginning to burn. The converter is then tilted in the direction of the arrow to pour the charge into a ladle. The product thus obtained is copper about 98 or 99% pure, known as "blister copper," because of the blisters on its surface due to expelling sulphur dioxide as the metal cools.

The last stage is the refining of blister copper either by the *poling process* or by *electrolysis*. The object is the same in both cases, viz., to remove the remaining sulphur, iron, copper oxide, antimony, arsenic and other less frequent impurities. The purpose for which the copper is to be used and the kind of impurity it contains determine the degree of refining necessary, though not over .5% of combined impurities should remain in any grade of refined copper.

64. The Poling Process.—This consists of melting blister copper in a reverberatory furnace and stirring it to bring about the chemical action necessary to remove the remaining impurities.

A charge is melted under the heat of an oxidizing flame and its surface is agitated by means of a heavy hoe, or rabble, to bring the impurities in reach of the flame. This is called "flapping." Samples of metal dipped from the furnace during this process enable the rabbler to judge its progress.

When the oxidizable impurities are burned out, the next step is to remove the copper oxide. The slag produced by flapping is drawn off, the furnace flame is changed from oxidizing to reducing, and the metal is covered with charcoal. Wood poles are then used to stir the charge. These supply carbon which assists the charcoal to reduce the oxide, forming CO_2 which escapes up the chimney. Green wood is best, as its moisture boils out and helps agitate the molten metal to bring carbon and copper oxide in mutual contact.

When the oxide is removed, the copper is tapped from the furnace into a large ladle and is poured into moulds made of copper. The molten metal is kept from sticking to the moulds by a wash of thin clay, and the red-hot pig or slab of metal is dumped into a trough of water to soften it for working.

Poling requires much skill and experience to know when it has proceeded far enough. Too much poling produces brittle copper.

65. Electrolytic Refining of Copper.—The malleability of copper and its efficiency as a conductor of electricity are greatly reduced by even the slightest impurities in the metal. The electrolytic process of refining is used because it gives a higher grade of refined metal from a greater range of impure copper than is the case with the poling process.

Electrolytic refining consists of dissolving plates of blister copper by electrolysis and depositing the metal from solution upon a previously prepared sheet of pure copper. The current gradually dissolves the plate of blister copper and deposits the metal almost absolutely pure upon the other plate. The impurities from the dissolved sheet either go into solution in the liquid of the tank in which the process is carried on, or fall to the bottom in the slime.

A plate of copper thus prepared is too porous for use, hence it is melted and cast into cakes, ingots or wire-bars, as may be needed.

66. Zinc is obtained from the sulphide, or "blende"; and to a smaller extent from the carbonate and oxide. There are several complex zinc ores, and some of these, as the zinc and lead sulphides, are abundant, but so far no method has been found for the profitable extraction of the metals.

The essential steps in extracting zinc are:

(1) Changing the ore to an oxide, by calcining the less stable ores and roasting the sulphides. Calcining is done in kilns, and roasting is done in reverberatory furnaces.

(2) Reducing the oxide. This is done by mixing the pulverized oxide with carbon and heating in clay retorts. The high heat necessary to accomplish the reduction (1900° F.) not only liberates the zinc, but vaporizes it, and the vapor is condensed in suitably placed iron tubes which drain the liquid zinc into ladles from which it is poured into ingots.

(3) Refining the ingots. They are remelted in quantities of several tons in a specially constructed reverberatory furnace. The molten metal is allowed to remain quiet for a few days, when the floating impurities are skimmed off. Molten lead and iron, which are almost always present, sink to the lowest part of the furnace basin and are quietly tapped out, the lead running out first, followed by the iron, which carries some zinc also. The remaining zinc is run out and cast into slabs or ingots for marketing. These are known as "spelter," and should contain not over 1% of lead and only traces of iron.

A recent refining process for zinc consists of passing the vapor from the reducing retorts through a filter of coke kept hot enough to prevent condensation. This is said to remove iron and lead better than by the method of re-melting.

67. Tin is produced from its oxide (SnO_2) known as stannite, casserite, or tin-stone, which is not so abundantly distributed as are ores of many other metals. The oldest mines are in England and the East Indies, though ore deposits in Europe and America are now worked. The best grade of commercial tin is said to be from Banca, in the East Indies.

68. Lead is produced mainly from its sulphide, known as galena. The smelting of this ore is complicated by the presence of arsenic, copper, iron, zinc, or silver, and like the smelting of copper sulphides, the process is one of desulphurization. The blast furnace, usually of rectangular cross-section, is now generally used for smelting lead, though if the ore is rich in sulphur, it is first roasted in a reverberatory furnace to drive off sulphur and oxidize some of the ore. A flux of iron oxide and limestone assist in reducing the ore, and the impure metal is drawn off through an opening in the base of the furnace leading outward and upward from the bottom of the hearth.

69. Nickel is produced from the arsenide, known as kupfernickel, and to a lesser extent from the sulphide.

The smelting process is somewhat complex and is accomplished by roasting, reducing in presence of flux, and Bessemerizing. The sulphide is then changed by roasting to oxide, which is finally reduced with charcoal.

70. Aluminum never occurs free in nature, but no other metal known, not excepting iron, occurs in such abundance in its compounds, nor is any other metal so widely distributed over the earth. Its combination with oxygen, silicon, alkalies and acids forms clay, koalin, emery, mica, feldspar and many of the precious stones. It is obtained mostly from Bauxite, an oxide known as alumina, first found near Baux, in France. This is dissolved in a fused bath of cryolite (a fluoride of sodium and aluminum) by the heat of an electric current. This heat fuses the cryolite, which in turn dissolves the alumina, in which condition the electrolytic action of the current decomposes the alumina, but does not change the cryolite. The liberated metal sinks to the bottom of the vessel and is siphoned off when it accumulates. The process is continuous so long as alumina is supplied and the current is maintained.

71. Electricity in Metallurgy.—Electrolytic action has long been applied to electro-plating, and in recent years to the refining of copper. The combined electrolytic and heat actions of current are used in producing aluminum, and very recently the heat of the electric arc has been made commercially successful in refining steel from a lower quality to a higher quality.

The advantages of the higher heat of the electric furnace, and its easy control, make the application of electric heat to the smelting of metals highly desirable, at least to the extent of (1) assisting the fuel at the point of ore fusion, (2) of making the extracted metal more fluid, and (3) of improving its quality by producing a neutral atmosphere due to electric heating as compared with the oxidizing atmosphere of fuel heating. Also, as some impurities come from the fuel used, the reduction in fuel reduces the per cent of these, particularly so of phosphorus.

Recent experiments in Sweden have shown that an improved grade of iron can be made in a combined electric and fuel furnace, but as yet this is not economical enough for commercial requirements in general.

CHAPTER III.

FUELS.

72. Uses.—The use of fuels of different kinds is highly essential in the various industries for the producing and shaping of metals. Heat is indispensable (1) to bring about chemical action which breaks up the ore compounds in the smelting of metals, (2) for many chemical and mechanical operations as the refining of metals and the making of wrought iron and steel, and (3) for softening or melting metals to assist in their shaping for definite uses.

73. Combustion.—The economical use of fuel requires that none of it should be wasted in an unburned state, as is frequently the case in the escape of unburned gases up the chimney. *Combustion* is the chemical union of an oxidizable substance with oxygen, and when this is accomplished rapidly, as in ordinary burning, an intense degree of heat is generated. Flame is caused by the burning of gas. The flame from solid or liquid fuel is caused by the burning of gas distilled from the fuel. The presence of fuel in many metal producing and metal shaping operations is objectionable (though unavoidable) for the following reasons, viz.: in the presence of high heat (1) the oxygen necessary for combustion consumes more or less of the metal or other material subjected to the operation, and (2) the substance of the fuel, and particularly the impurities in the fuel, combine with a metal in the process of smelting and in subsequent heating or melting operations and impair its quality.

The essentials for burning fuel completely, with no visible smoke and no waste of combustible substance, are (1) every particle of combustible substance must be supplied with the oxygen necessary for complete oxidation, and (2) the fuel and the oxygen must be hot enough to combine.

Every combustible substance must be heated up to a definite temperature, called the temperature of ignition, before it will burn. Each burnable substance has a temperature of ignition differing more or less from that of other substances.

In the confined space of a furnace, coal in small lumps or porous coke present much surface to combustion and therefore burn rapidly, but if coal is too fine, it masses together and leaves too little passage for air.

74. Components of Fuels.—The heat-producing elements, *i. e.*, the combustible substances, of all fuels, whether solid, liquid, or gaseous, are carbon and hydrogen. Many fuels, particularly coal, contain free sulphur, which is always more or less objectionable, sometimes seriously so, and although sulphur produces heat when burned, its quantity is too small to be considered in summing up the heat value of a fuel.

Almost all fuels contain ash, water and other matter which will not burn, and these determine largely the practical and commercial values of all fuels. These are of negative value in fuel, as they absorb and carry away heat when the fuel is burned.

The heating or calorific value of a fuel is usually expressed in British Thermal Units. One B. T. U. is that quantity of heat necessary to raise the temperature of one pound of pure water through 1° F., at or near 39.1° F., its point of greatest density. The heat value of a fuel is stated as that quantity of B. T. U.'s which one pound of the fuel will evolve when burned.

In commercial practice, fuel is usually sold by weight, but the heat value of a fuel is only crudely expressed by its weight. The value of a fuel for practical purposes is far better expressed by the number of heat units which a given weight of it will supply when burned. The desirability of coal is also determined by the sulphur it contains, and by the character and quantity of the ash it makes, as some coals produce a sticky clinker hard to remove from the grate bars.

75. Classes of Fuel.—The following classification includes all fuels in general use in the arts and industries. Some of these have but limited and special uses in the metal industries.

- (1) Solid Fuels.
  - (a) Natural Fuels.
    - Wood.
    - Peat.
    - Coal.
  - (b) Prepared Fuels.
    - Charcoal.
    - Coke.
    - Powdered Coal.
    - Briquettes.
- (2) Liquid Fuels.
  - (a) Natural Fuels.
    - Mineral Oils.
  - (b) Prepared Fuels.
    - Refined Mineral Oils.
    - Alcohols.
- (3) Gaseous Fuels.
  - (a) Natural Gas.
  - (b) Prepared Gases.
    - Producer Gas.
    - Water Gas.
    - Illuminating Gas.

76. Wood and Charcoal.—Wood is less and less used as fuel because of its increasing scarcity and because coal is abundant and easily handled. Charcoal, made from wood, is now used only for special purposes because of its high cost. Charcoal is prepared by heating wood to a high heat and thereby distilling off nearly all water and volatile gases, leaving only carbon and non-combustible mineral salts. The heating must be done under a covering which will exclude air.

In later processes, charcoal is produced in kilns, or in closed retorts in which wood is distilled for pyroligneous acid and wood alcohol, and charcoal is a by-product.

77. Coal is the most extensively used of all fuels. The different varieties of coal, with many different names, merge one into another, and the fundamental distinction between the several varieties is the difference in the amount of carbon contained. The several grades or qualities of each variety are due to the per cent of sulphur, ash and water contained. Coal usually contains some phosphorus.

A good practical classification of the varieties of coal is:

(1) Bituminous or soft coal.

- (a) Non-caking varieties, long flame and gas coals, 40 to 70% fixed carbon.
- (b) Caking, or coking varieties. Short flame coals, 55 to 80% fixed carbon.

(2) Anthracite or hard coal, 80 to 95% fixed carbon.

There are many grades of each kind, beginning with lignite, a brown soft coal low in carbon, and ranging gradually through the bituminous to the anthracite coals which are very rich in carbon and contain very little hydrogen. The flame from coal is due to the gases which are distilled off by the heat of the fire and burn after they are thus liberated. Fixed carbon is the solid carbon in coal as distinguished from the gaseous carbon, which is that combined with hydrogen.

Bituminous coals constitute most of the world's supply. They are fragile, and burn with more or less flame and smoke. From this variety of coal, coal gas and coke are made. Cannel coal is a variety of bituminous coal.

Anthracite coal has a lustrous black color, is hard, and does not readily pulverize in handling, hence is comparatively free from dust. The best varieties give off very little gas, hence they burn as incandescent coals with very short flame. The purer varieties are used in smelting furnaces occasionally, and more frequently to melt metal in crucibles.

78. Coke is a product of bituminous coal, bearing the same relation to coal which charcoal bears to wood. The better varieties, made from the softer bituminous coals, and used almost entirely in the blast furnace and for melting metals in the foundry, are primary products, while the poorer varieties are by-products from the manufacture of coal gas. A good grade of coke must be porous, yet not fragile, for it must not be crushed by the weight of the charge in a furnace; and it must contain little sulphur or ash, which requires that it be made from a good grade of coal.

79. Coke Making.—Coke is made by subjecting coking coal to a high heat for about four days, without free access of air. This process drives off water and the hydrocarbon gases, leaving the free

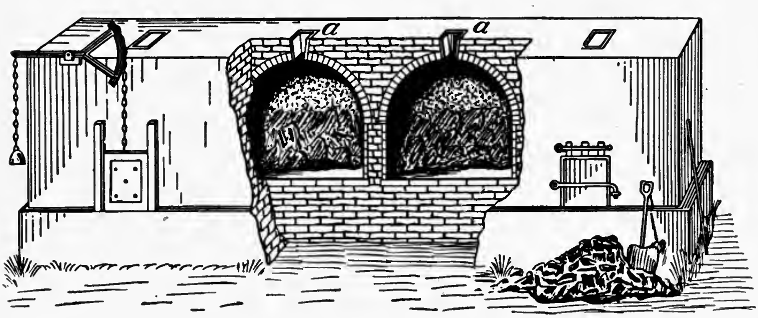


Fig. 12.—Coke Oven.

carbon and ash. Coal should be selected which contains little sulphur, as all of this is not driven off in coking. Fig. 12 shows a simple type of coke oven which is still used, though more elaborate and more economical ovens are displacing it. This type, known as the bee-hive oven, is shown here because of its simplicity. This form of oven is low in cost to build and to maintain, and is a good coke producer. A number of ovens are built together to economize space and heat. This oven is a chamber formed of brickwork, lined

with fire brick, and provided with an opening *a* in the top and a door at the side. Two styles of doors are here shown in two of the ovens. Doors are lined inside with fire brick, and are provided with dampers. The lower part of the chamber is circular, about 10 ft. in diameter, and is surmounted by a hemispherical dome.

A charge of coke having been removed through the door, the oven is left at a dull red heat. The door is closed and luted with clay, except that a few peep holes are left for watching the process and for admitting air for combustion. A charge of several tons of coal is dumped in at the top opening from a car which moves along rails laid over the furnaces. The furnace heat soon begins to distil off the gaseous parts of the coal, which are ignited by the admission of air at the dampers, and this combustion supplies heat which continues the coking process. It requires several hours for the charge to get thoroughly hot throughout, and the distillation of gases gradually extends into the mass, and when a maximum amount of gas is being evolved, the furnace lining and charge are at a red heat. After about thirty hours the evolution of gas begins to decrease, and a little air continues to be admitted until all flame ceases, when air is shut off entirely. The furnace is now nearly white hot, and combustion is stopped entirely, for the charge must cool down before it can be withdrawn. After about twelve hours the charge has cooled to a degree which will allow a limited amount of water to be introduced from a hose for quicker cooling, and after a short time the door can be opened wide and the charge raked out into iron barrows.

In this type of furnace the products of distillation escape partially burned through the top opening, and may be completely burned elsewhere, as they are rich in combustible gases. It is sought in coking to heat the mass of coal from above by burning some of the distilled gases before they escape from the oven, but the burning of some of the solid carbon is unavoidable, hence this furnace is not so economical as some of the later types.

80. Powdered Coal has a limited use in metal heating furnaces. It is ground to a fine dust by revolving it in a steel drum with hard pebbles. It is then conveyed through tightly made sheet iron tubes to the furnaces, and is blown into the flame of the furnace by air pressure through a specially constructed burner for regulating both air and fuel.

81. Screenings. Briquettes.—In handling coal at the mine, a considerable quantity becomes pulverized. In this form it is known commercially as *screenings*. This is now used in mechanical stokers fitted to steam boilers, and some of it is made into briquettes by mixing it with tar or crude oil and pressing it into cakes by a machine for that purpose. Some grades of screenings must be washed to remove mineral matter.

82. Liquid Fuels.—The only practicable cheap liquid fuel is mineral oil, better known as crude petroleum, though this is confined to too few localities for general displacement of coal, but in those localities is usually cheaper and more desirable than coal. It comes from oil wells drilled usually deep into the earth. When taken from the earth, this oil is refined before it can be safely used for fuel. This consists of subjecting it to two stages of distillation which causes it to give off in turn highly inflammable gases, gasolene, benzine, and naphtha; then kerosene, and gas-enriching oils, leaving a dark-colored viscous liquid residue which is used as fuel. Fuel oil must be strained and frequently is heated just before it is burned to increase its fluidity and prevent clogging the burners. It is sprayed by pressure into the furnace.

While all mineral oils consist of the same elements, carbon and hydrogen, the oils from different localities vary widely in the relative amounts of gasolene, kerosene, lubricating oil, and the more dense constituents forming the residue, due to the fact that carbon and hydrogen have a great variety of chemical combinations, and each of these combinations, or compounds, differs in volatility from the others. This accounts for the fact that some mineral oils have a large proportion of volatile oils and only a small amount of residue, while others have a large proportion of residue and need but little distillation to prepare them for fuel. The residue of mineral oils includes the heavier lubricating oils, vaseline, paraffin, and mineral pitch better known as asphalt or bitumen. Mineral oils contain more or less earthy impurities, including sulphur. It is not known from what sources mineral oil was produced in its natural deposits.

Of the refined oils, gasolene is much used as motor fuel, and kerosene has very limited use as an industrial fuel.

Alcohols are produced from fermentation and distillation of

vegetable matter and make excellent fuels, but they are little used at present except in small quantity for special needs. They are considered superior to petroleum fuels for motors, but their production and development for this use is limited because of the extensive use gained by gasoline while it was very cheap.

83. Gas Fuels.—The great convenience of natural and producer gas as fuel in reverberatory, steel-making, and metal-heating furnaces has caused extensive use of gas fuel in all metal industries.

For furnace use a more concentrated and more intense heat can be obtained from gas than from coal, as a less volume of air enters the furnace with the gas, thus necessitating the heating of less inert nitrogen which enters with the air. The heat from gas can be regulated and directed better than that from coal, and gas leaves no ash nor clinker.

84. Natural Gas, like mineral oil, is obtained from cavities in which it is confined in the earth. It is abundant in a few localities only, but the great desirability of gas has given rise to the artificial production of fuel gas from coal, and to a less degree from oil. Natural gas is composed of about 93% CH_4, with very little free hydrogen, CO, and nitrogen.

85. Producer Gas is made as follows, referring to the gas producer in Fig. 13. A shell of steel plates, lined with fire-bricks, rests on a cast-iron ring *A*, which in turn is supported by lugs resting on the edge of a basin *B*. This basin, which is a depression in the concrete floor, is kept filled with water. The interior of the producer contains fuel in various stages of burning, varying from water-soaked ashes in the basin at the bottom to a continuously supplied layer of fresh fuel at the top.

By means of a central tuyere with a mushroom head *G*, steam from the pipe and nozzle marked *C*, and air drawn through the damper *D*, are blown into and distributed through the fuel, entering the hot ashes at *G*, and rising through the zone of incandescent fuel. When the air and vapor become sufficiently heated, the oxygen of the air combines with the carbon of the fuel. The tendency of this combustion is to form CO_2, but the relatively small quantity of oxygen carried in by the air in presence of a large amount of incandescent carbon soon reduces the CO_2 to CO. The heat produced by combustion is intense enough to decompose the

water vapor, the oxygen combining with the carbon of the fuel and the hydrogen rising uncombined. The gases resulting from this partial combustion of fuel and the hydrogen resulting from the decomposing of steam rise into the space above the fuel and pass away through the outlet *K* into "scrubbers" or cleaning compartments, thence into the storage tanks ready for use.

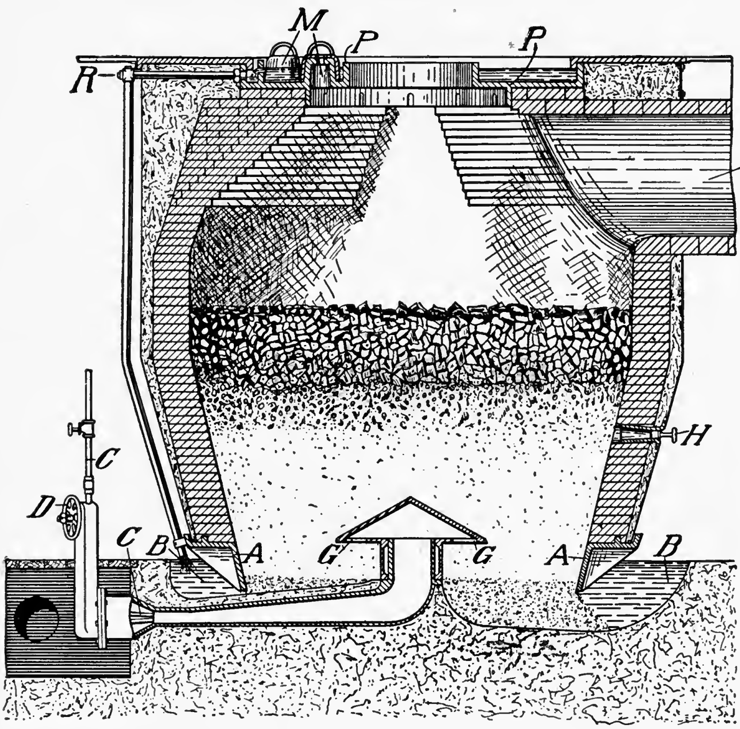


FIG. 13.—Gas Producer.

The central opening at the top is the seating for an automatic feeder (not shown in the sketch) regulated to drop fuel into the producer continuously at the rate needed. Fig. 14 shows a row of these feeders, surmounted by coal hoppers, along a working floor over the producers. The brick-work forming the body of the furnace, as shown in Fig. 13, is closed at the top by a cast-iron pan *P*, which holds water for keeping the top cool. This water is received

from a small pipe and flows from the pan into the ash basin through a small pipe R in the quantity needed to keep the basin B about full. It serves also as a water seal both in pan and basin to prevent the escape of gas from the producer. The fuel is poked through the holes H on the side and through the water-sealed holes M on top if it becomes clogged. The small covers for the water-

FIG. 14.—Automatic Feeders for Gas Producers.

sealed holes on the top are shown at the floor level in Fig. 14. Ashes are removed from the basin at the bottom of the producer.

The gas product passing out at K consists essentially of (1) CO, from partial combustion of the fuel, (2) hydrogen from the decomposed steam, (3) and a small quantity of hydrocarbon gas distilled from the coal as it heats up before beginning to burn; these are the combustible gases and should be about 50% of the whole volume of gas produced for maximum efficiency of a producer. The remain-

der of the mixture consists of (4) a slight amount of CO_2 from complete burning of the fuel, and (5) considerable nitrogen unavoidably entering as a constituent of air.

The relative amounts of air and steam blown in must be carefully regulated. With no steam, the combustion would need much more air, resulting in larger proportions of nitrogen and CO_2, as well as in too intense a heat in the producer. Steam is advantageous because it (1) displaces nitrogen; (2) absorbs heat in its decomposition, thereby keeping down the temperature of the producer; (3) supplies oxygen for combustion, and (4) hydrogen for enriching the gas product. Too much steam checks combustion by displacing air and by lowering the temperature of the furnace below that required for burning the fuel.

Producer fuel for metallurgical work usually consists of the ordinary grades of bituminous coal, including lignite. Usually the cheapest grade of coal in the locality where the producer is installed is suitable provided (1) it does not contain an excessive amount of sulphur nor (2) a large per cent of ash which forms pasty clinkers. The richest gas is made from gas coals because of the volatile hydrocarbons they give to the producer product. The fuel for a producer should be in small lumps, because coal which is wholly "slack" or very fine will resist the passage of air and steam. There are several varieties of gas producers but all embody the same principle.

86. Water Gas is produced by forcing steam through a network of very hot fire bricks, on the principle of the blast stove, and immediately, while at a high temperature, through a bed of incandescent fuel. The hot fuel decomposes the steam, consuming the oxygen, liberating hydrogen and giving off CO. In this way no nitrogen is introduced. The blowing of steam through the fire is intermittent as it soon cools the fire and must be shut off to allow the fire to regain heat by ordinary combustion. Water gas produces a more intense heat than does producer gas, but is used only for special needs as its cost is greater than that of producer gas.

87. Illuminating Gas is made in closed retorts from coals rich in gas, and is too expensive for extensive use as fuel in mechanical industries.

CHAPTER IV.

IRON AND STEEL.

I. Iron Ores and Their Reduction. Pig Iron.

88. Iron Ores.—These ores are very widely distributed and very abundant in nature, but many deposits cannot be worked profitably. According to chemical composition, ores available for smelting may be classified as follows:

I. Magnetic Iron Ores, or Magnetite (Fe_3O_4).

II. Ferric Oxides or Hematites (Fe_2O_3).

III. Ferrous Carbonate or Spathic Ores ($FeCO_3$).

IV. Iron Pyrites (FeS_2, iron sulphide or fools' gold) is a very abundant ore, but cannot be cheaply smelted because of the difficulty of eliminating the sulphur. However when the sulphur from this ore is extracted in the manufacture of sulphuric acid, the remaining product is profitably smelted, though the iron obtained by this means is but a very small per cent of that smelted.

The *magnetic ores,* the most valuable of all iron ores, are black, very dense, not so widely distributed as the other ores, have magnetic properties and contain about 72% of iron when pure. The largest known deposits are in the Lake Superior region of the United States.

The *hematites* are usually red or brown in color, according to the gangue, are widely distributed, and usually free from excessive sulphur and phosphorus. They are employed more in smelting than are other ores because of their abundance.

89. Preliminary Preparation of Iron Ores.—Upon taking iron ore from the mine, which is usually a simple process of excavating after surface earth is removed, it is desirable to remove the gangue, if this exists in large quantity, to avoid the labor and expense of its further handling. Magnetic ore may be lifted away from gangue by electro-magnets, a process known as *magnetic concentration.* Other methods of removing gangue have been mentioned.

90. Calcination.—The main results of calcination, and the consequent advantages in smelting are, for iron ores:

(1) Driving off water and thus avoiding interference with the regularity of the smelter fire.

(2) Elimination of CO_2 and a consequent saving of fuel in smelting as the CO_2 takes up much carbon from the fuel in the upper part of the blast furnace. This changes the carbonate ores to oxides.

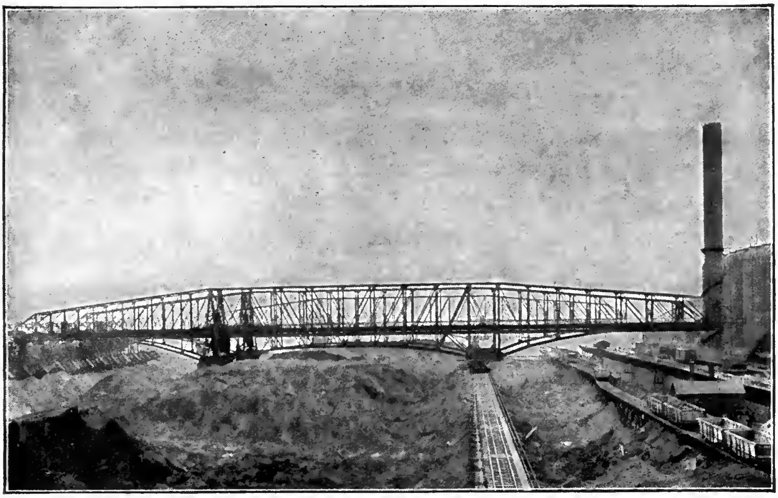


Fig. 15.—Bridge crane for handling ore. The unloading hoists on the left take ore from vessels lying under them and pass it to the bridge crane in transfer cars. This crane carries it to its proper pile, according to composition, and also carries ore to the charging cars of the furnaces on the right.

(3) Elimination of sulphur in some ores, thus preventing its combination with the metal as it melts and runs down to the hearth of the furnace.

There is no advantage in calcining the magnetites and red hematites unless they contain pyrites. Ore deposits of the world which can be sent direct to the smelter without sorting or calcination are yet fairly abundant.

Fig. 15 shows the ore yard of a large smelting plant where ore is received for smelting.

91. Reduction.—Iron ores are always reduced in the blast furnace, the parts and operation of which have been described (Pars. 53 and 57. The process of smelting iron is very simple, as the ores used are oxides, uncombined with other metals, and merely mixed with gangue, which is removed by combining with the flux in the charge. The simplicity of the process consists in the fact that all of the chemical changes take place in one operation.

The important changes are as follows: The highly heated air forced in at the tuyeres at once spreads through the charge which fills the furnace. Coming in contact with the incandescent fuel, the oxygen of the blast and the carbon of the fuel unite, forming CO_2. The CO_2 meets more carbon as it rises and gives up part of its oxygen, forming CO. This is a powerful reducing agent and, with some complexity of reaction, it reduces the ore, and at the same time the flux combines with the gangue. Metallic iron and slag are thus formed, and as they sink into the fusion zone, both melt and run down.

In the intense heat of the fusion zone, some of the compounds of silicon, sulphur and manganese, and usually all the phosphorus compounds are decomposed, and these elements enter the molten iron. At the high heat of the modern blast furnace molten iron also dissolves some carbon, hence when the iron settles on the furnace hearth it has carried down with it small amounts of silicon, phosphorus, sulphur, manganese and carbon, which are always present in ore, flux, or fuel, but which have a great affinity for iron and remain with it when tapped from the furnace.

92. Pig Iron.—The product of the blast furnace is pig iron. From this all other forms of iron and steel are now made. Some grades of pig iron are selected, and without further change are merely re-melted in the foundry for making castings, hence it has become common for the designations "pig iron" and "cast iron" to be interchanged.

All pig iron contains an aggregate of about 7 per cent or less of the five substances, carbon, sulphur, phosphorus, silicon and manganese, and the grade or quality of pig iron for various uses is determined by the amounts of each of these ingredients contained.

Iron occasionally takes up other substances in smelting, but these are usually negligible.

For high-grade uses demanding an iron of superior ductility and chemical purity, a limited quantity of "charcoal iron" is at present smelted. Ores of exceptional purity are selected (particularly free from sulphur and phosphorus) and are smelted with charcoal fuel. A cold blast of air causes the iron to dissolve less carbon than it dissolves in the higher temperature of the hot blast, also a lower smelting temperature lessens the introduction of other ingredients into the iron, hence the superiority of "cold blast iron."

The name "pig iron" comes from the former way of running iron from the blast furnace along channels and branch channels, in herring-bone shape, in the level sand bed adjacent to the furnace. The iron along the main channel was called the sow, and that in the branch channels was called the pigs.

93. Disposition of Iron from the Blast Furnace.—When iron is tapped from the furnace, it is the practice at present to convey it by means of a trough or trench into a large ladle, even if it is to be cast into pigs. Fig. 16 shows iron flowing along a trench from the furnace, on its way to the ladles, and Fig. 17 shows the metal flowing into ladles. Large ladles hold about 50 tons, and are either supported on a car and hauled by a small locomotive, or are lifted and transported by a traveling crane. The ladle contents may be disposed of in any of the ways below stated, depending upon the purpose for which the smelter product of a particular composition may be suited.

(1) Poured into a large reservoir called a "mixer" which maintains a supply of molten metal (designated as "hot" or "direct" metal) for:

- (a) Making steel by the open hearth process.
- (b) Making steel by the Bessemer process.

(2) Poured into pig moulds made of heavy iron to be re-melted later for:

- (c) Making iron castings in the foundry.
- (d) Making wrought iron in the puddling furnace.
- (e) Uses stated in items (a) and (b).

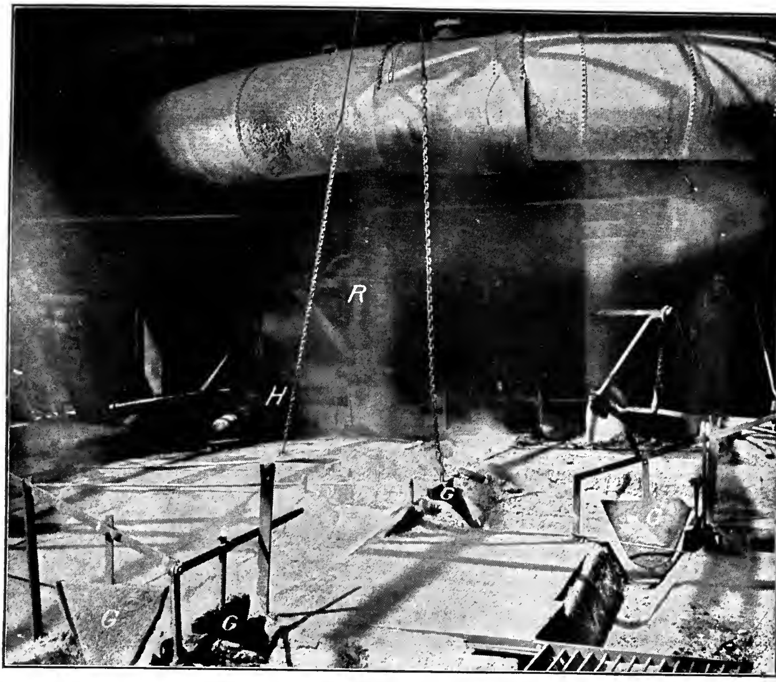


FIG. 16.—Base of a Blast Furnace showing iron flowing from the furnace along trenches conveying it to ladles. The stream is directed along the trenches by the gates *G*. When the flow of iron from the furnace is to be stopped, the "mud gun" *H* is swung around on its crane *R* in front of the tapping hole. It operates a piston rod by hydraulic power and forces a cone of clay into the tapping hole.

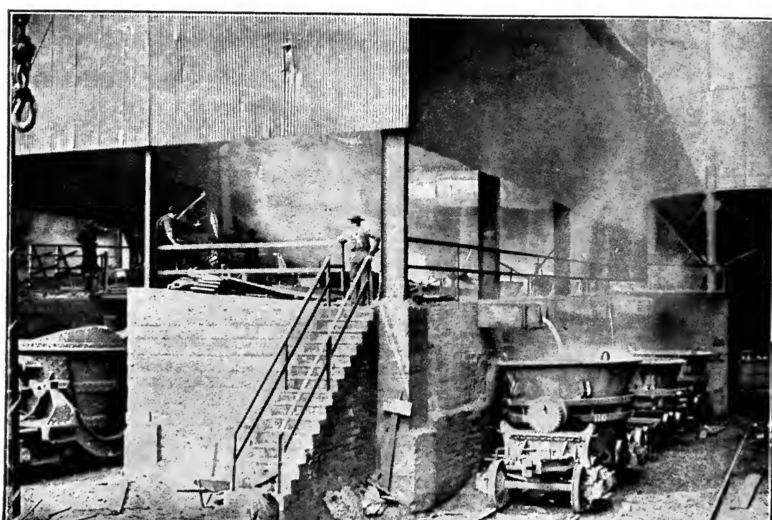


FIG. 17.—Ladles Receiving Molten Pig Iron from Blast Furnace Troughs.

94. Grades of Pig Iron.—The grade of iron which a furnace is producing is governed within certain limits by the chemical make-up of ore, fuel, and flux, but the composition of these elements of the charge is not always uniform, nor are heat conditions in the furnace always the same. These variations give rise to iron of various compositions, within certain limits, and when iron is cast into pigs, a sample from each heat is analyzed chemically, to determine the per cent of each of the five ingredients named, and the iron is graded from this analysis.

In the old way of casting iron into pigs in the sand bed, the cast had to be broken up to be removed. This gave opportunity to inspect the fracture and judge approximately the quality of the iron from its carbon. These fractures showed either grey, mottled, or white color, in the order of the uncombined carbon which the iron contained, and by these colors the iron could be graded for its suitability for different uses. The grey iron is soft and used mostly in the foundry, as it makes excellent castings and can be easily machined. The white iron, on the other extreme, is hard and brittle, difficult to cut, and is best adapted for steel or wrought iron making.

Various grades of pig iron are named from the locality or company which produces them, particularly in England.

Buyers of pig iron now purchase their iron according to its chemical composition, and not according to its trade name, nor according to inspection of fracture. The American Society for Testing Materials has recommended that in each car load of pig iron, one pig in each four tons shall be selected for sampling and analysis.

II. The Classification, Ingredients and Properties of Iron and Steel.

95. The Three General Classes.—It is essential to understand the difference between the several classes of iron and steel, and the effects of the substances which they always retain from the blast furnace. These substances are frequently spoken of as impurities, but some of them are always more or less desirable in the iron in giving it certain properties. It may be stated that chemically pure iron is not known, except possibly as a laboratory curiosity.

The three general classes of iron are (1) wrought iron, (2) steel, and (3) cast iron. Within each class there are many grades, due to the varying quantities of the substances which each grade contains. These substances affect the metal adversely or otherwise according to their quantity and the use for which the metal is desired.

All grades and classes of iron and steel gradually merge one into another, and the difference between them is due primarily to *carbon.* The approximate limitations of carbon contained by each class are as follows:

Wrought Iron	Trace to .08 per cent
Mild Steel (also known as "Ingot Iron," "Low Carbon Steel," "Soft Steel")	Trace to about 0.25 per cent
High Carbon Steel	About 0.25 to 2.2 per cent
Cast Iron	*2.2 to 4.5 per cent

Carbon in iron and steel has a direct effect upon their properties, and other elements usually contained govern somewhat the power of the metal to take up carbon, and their influence is both direct and indirect. Iron and steel are affected similarly by the same ingredients, and in discussing these the general term iron is meant to include steel.

It will assist, in the study of the several elements taken up by iron, to regard the metal in its molten state as a solvent which has a stronger tendency to dissolve some elements than others, and which, when certain elements have been dissolved, has a decreased or an increased power to dissolve other elements.

96. Carbon in Iron.—When iron is fused in smelting, it gets its first carbon, the amount depending upon its temperature, and upon the manganese, silicon and other substances present in the furnace. This amount increases with the temperature and is influenced in different ways by the other substances contained, but is rarely less than 1.8 per cent. When the metal solidifies, its carbon may assume either an invisible form, called combined carbon, in which case the

* The International Association for Testing Materials has, for specific reasons, based upon investigations of Messrs. Carpenter & Keeling, recommended that the line be drawn between steel and cast iron at 2.20 per cent of carbon.

metal shows a white fracture; or it may be visible in the fracture, giving a mottled or grey color, and known as uncombined carbon or graphite. The condition assumed by the carbon as the metal solidifies depends (1) upon the rate of cooling, and (2) still more on the kind and quantity of the other substances contained by the metal.

As with other solvents, iron forms a non-crystalline mass if cooled rapidly, and none of the carbon is precipitated, thus showing the white fracture of iron, but slow cooling allows formation of metal crystals, and, if the carbon is above 3%, some of it separates as uncombined carbon.

Carbon renders iron and steel hard, less ductile and more fusible, directly according to the amount contained, and it is well to understand that a small alteration in the amount of *combined* carbon has very marked effect upon the metal, while a moderate alteration in the amount of *uncombined* carbon has very little effect.

97. Silicon in Iron.—Cast iron ordinarily contains silicon up to 4% or slightly more, although "silicon pig," the form in which silicon is handled for foundry and similar uses, is made in the blast furnace containing up to 18% of silicon; and ferro-silicons, made by the electric furnace, may contain up to 95% of silicon.

Next to carbon, silicon is most important in determining the suitability of cast iron for foundry use, because its presence up to 2% assists the softness and fluidity of the metal. It softens the metal, making it tough and less brittle, by decreasing the per cent of combined carbon, which acts as a hardening element. Also, in increasing the fluidity of molten cast iron, silicon contributes to the prevention of blow holes in making foundry castings by allowing time for the gases formed or entrained in the molten metal to escape.

Beyond 2%, silicon renders iron weak and hard. The solution of carbon in iron is rendered more difficult by the presence of silicon, as iron dissolves silicon in preference to carbon.

98. Sulphur in Iron.—This element is particularly objectionable, but is always present in iron and steel, rendering them brittle when hot, a condition known as "red short" or "hot short." Iron and steel for high-grade forgings must not contain more than .04% of sulphur, although for castings the metal may safely contain up

to .15%. Sulphur in iron tends to cause the carbon to assume the combined form.

99. Phosphorus in Iron.—Neither the quantity of carbon dissolved in iron nor its condition as combined or uncombined carbon is much affected by phosphorus, but this element has the effect of hardening iron slightly. It is, however, highly objectionable in forged iron and only slightly less so in foundry iron for castings, as it causes brittleness when iron is cold, a condition known as "cold short," and may cause the metal to break, when worked cold or when receiving repeated shocks in use. It should not exist in iron for important forgings beyond .06%, nor in foundry iron for strongest castings beyond .5%, although it is used in railroad rails to harden them against wear. Iron high in phosphorus does not make good grate bars nor other castings subjected to high heat, as it renders them spongy.

Phosphorus renders molten iron very fluid and causes it to take an excellent impression of the mould, hence in small castings where strength is not the first requisite, iron may be used containing up to 1% of phosphorus.

Neither phosphorus nor sulphur can be avoided in iron making, and both are difficult to eliminate. The best means of keeping them below objectionable amounts is to select ore fuel and flux for smelting which are as free as possible from them, although materials for the smelter are seldom ideal and cannot always be selected as desired.

100. Manganese in Iron.—The smelting process always leaves in iron a small amount of this element. Up to 2% it increases tenacity and hardness, but beyond that amount it causes brittleness. It tends to eliminate sulphur and neutralize silicon, hence its effect within this range would act to render iron less hard by decreasing the hardening effects of these elements. Much manganese increases the soluble power of cast iron for carbon.

In foundry iron, manganese is added, if not already present, up to about 1.5% for its effect in making a hard, close-grained iron and in eliminating sulphur absorbed during re-melting for the purpose of casting.

In steel making, manganese is always added up to about .05% for improving the working qualities of the steel, particularly when hot.

The extensive use of manganese as an ingredient in steel making has made common two alloys of manganese and iron. One, known as spiegel-eisen, contains from 1.5 to about 20% of manganese, and presents a brilliant fracture. The other, known as ferro-manganese, contains from 20 up to 86%, has a light gray fracture and is so brittle that it may be readily pulverized in a mortar. Both of these products are obtained from the oxide of manganese, a mineral.

101. Properties of Cast Iron.—Cast iron is brittle, non-elastic, and the easiest fused of all iron, these properties varying directly with the amount of *combined* carbon and to a less degree with the amount of *uncombined* carbon contained. It can be cast into intricate forms and has the advantage of expanding upon cooling, but it cannot be forged, nor united by the usual welding process of heating and hammering. It it not malleable nor ductile, and cannot be hardened like steel, because it contains uncombined carbon. It has either a crystalline or a granular fracture, determined by rapidity of cooling, and melts at about 2100° F.

102. Properties of Wrought Iron.—In composition, wrought iron differs from cast iron and steel in two important features, viz.: (1) In having had removed, as an essential of its manufacture, the greater part of the five elements usually contained in iron. In this respect it is near the composition of mild steel. (2) In containing, as a result of the process of manufacture, a quantity of slag (usually called cinder) which surrounds each iron crystal in a thin sheath, and preserves the identity of the crystal as a fiber when a bar of wrought iron is elongated by rolling or hammering. In this respect it differs from steel, which is crystalline and without much slag.

The chief properties of wrought iron are as follows, viz.:

(a) It is very malleable and ductile, and can be readily forged, particularly when heated.

(b) It cannot be cast, as it is fusible only at a very high temperature (about 2800° F.), and merely becomes pasty at the usual furnace temperatures, though because of this quality it is readily united by welding.

(c) It cannot be hardened, due to lack of carbon.

(d) If pulled apart, the fracture shows a fibrous break.

Wrought iron gets its name from the fact that it may be wrought into various shapes readily under the hammer; also it is called *malleable iron* in England, because of its great malleability, but it must not be confused with *malleable castings,* also called *malleable cast iron* or merely *malleable iron* in America.

While wrought iron and mild steel resemble each other, there are certain distinct advantages of wrought iron which cause it to be retained for some uses. Among its advantages are (1) it welds better than does steel, (2) lasts longer when exposed to weather or to water, (3) is better to resist shock and vibration (fatigue), in use, and (4) its fibrous structure arrests fracture, as its breaking is in the nature of a gradual tearing, which often gives warning of a dangerous stress, while steel breaks suddenly.

Among the disadvantages of wrought iron are, (1) its elastic and tensile strength are lower than those of steel, (2) and its production is more costly.

103. Properties of Steel.—When steel first came into practical use, its distinguishing characteristic was its ability to harden if heated to a red heat and cooled suddenly, as in water or oil. Present methods of steel making have, however, brought out a product of iron containing too little carbon to harden when cooled suddenly, yet its composition differs from the old form of steel only in containing less carbon.

Primarily, the differences between wrought iron, the several grades of steel, and cast iron are due to the per cent of carbon in each class of metal, and for this reason steel is said to occupy a place between wrought iron and cast iron. However, the processes of manufacture give steel a composition and a molecular structure which affect its properties aside from this simple relation. The properties of steel depend primarily upon the carbon it contains, influenced by the kind and quantity of the other ingredients (or impurities, they may be called), and further influenced by the cooling of the steel from its molten state. This last-named influence determines the size and composition of the crystals which steel assumes upon cooling.

Despite the somewhat complex conditions determining the properties of steel, the grades of steel are classed according to their hardness due to their contained carbon. The higher the per cent

of carbon, the greater the strength and brittleness, and the less the elongation before breaking. The grades of steel merge so gradually one into another that only two classes are distinguished, viz., *mild steel* which will not harden when suddenly cooled, and *high-carbon steel* which will harden when suddenly cooled from a red heat. This property of hardening begins to show when the steel contains .25% of carbon though is not of much practical use in hardening tools until the carbon has reached about .75% in the steel.

A quick means of showing whether a piece of iron is wrought iron or steel is to place it in a somewhat dilute mixture of sulphuric and hydrochloric acids, after it has been cleaned to show a metallic surface. Steel shows a granular and wrought iron shows a fibrous structure after a few minutes action of the acid.

The conditions determining the properties of iron and steel can only be touched upon lightly here, and the pursuit of this subject is in itself a special study.

III. The Manufacture of Wrought Iron.

104. History of Wrought Iron.—Wrought iron is the form in which iron was probably first known to man. The ancients reduced it directly from the oxide ores in small furnaces, using charcoal as fuel and depending at first for a blast upon the pressure of a strong wind to force air through a tuyere in the side of the furnace. The heat generated was barely sufficient to reduce the ore, and not high enough to cause an absorption of carbon to any degree, nor the decomposition of the silicon, phosphorous and manganese compounds. The iron, mixed with cinder and slag, was taken from the furnace in a pasty state (because it did not melt at the temperature of the furnace) and was hammered to squeeze these substances out.

This process was improved and enlarged, until finally the blast furnace was developed. As the degree of heat in the reducing furnace became higher, due to a closed furnace, thicker walls, more tuyeres and more rapid combustion of the fuel by improved methods of supplying a pressure blast, the production of pig iron gradually resulted in place of wrought iron.

Wrought iron was produced from the ore merely because the heat was not high enough to make the metal take up carbon, the absorption of which would have changed the product to pig iron.

105. Methods of Production.—This method of producing wrought iron direct from the ore is called the *direct method.* It it still used to a small extent in a few places in Europe where charcoal is cheap, but its output is not important in the commercial world. The method by which most of the wrought iron is now produced is known as the *indirect method.* It is so named because the ore is first smelted to produce pig iron, and this is then converted into wrought iron.

106. The Indirect Process of Wrought-Iron Making.—This process consists essentially of the following steps, viz.:

(1) Melting pig iron in a form of reverberatory furnace called a *puddling* furnace, and burning out the impurities principally by oxygen supplied from iron oxides.

(2) Subjecting the product of the furnace, after its removal therefrom and while in a hot and plastic state, to mechanical treatment to press out furnace slag.

(3) Cutting into short pieces the bars of impure iron resulting from the preceding step, binding together, re-heating, then hammering or rolling. This eliminates more slag, welds the several pieces of the mass thoroughly, and shapes it into plates or bars for market.

Carbon and other impurities are seldom entirely removed, but are merely greatly reduced in quantity. It is impossible to burn out carbon and other impurities without also burning some of the iron.

107. The Puddling Furnace.—Fig. 18 shows two sections of a double puddling furnace, built double to save space, building material and heat. This furnace is built of common brick, and lined with refractory brick. It is held together by vertical iron braces spaced along the sides and connected across top and bottom by tie rods.

A particular feature of the puddling furnace is its hearth. Beside forming a basin for holding the molten contents of the furnace, the materials of the hearth have an essential chemical purpose in assisting the changes brought about by the process.

The foundation of the hearth is three cast-iron plates resting on masonry supports. Hollow cast-iron air-chambers, *AA,* rest on these plates and extend through the sides of the furnace, opening

into the air. These strengthen the ends of the hearth and assist greatly in relieving the fire and flue bridges of the intense heat.

The hearth is made of furnace slag and iron ore. This slag is composed mainly of iron oxide and silica and is called cinder. The hearth is prepared by fusing large and small lumps of ore and cinder upon the plates to a depth of about 6 inches. The sides of

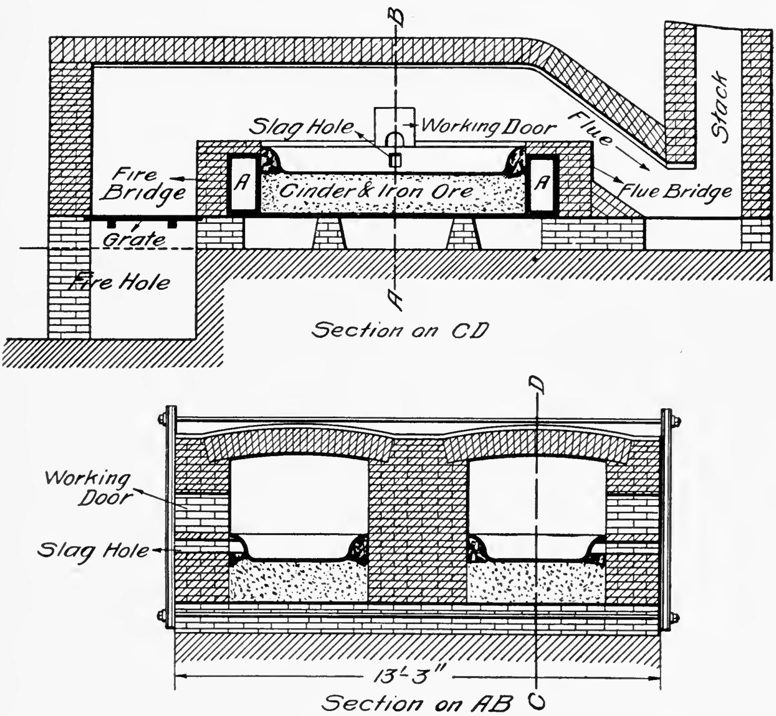


FIG. 18.—Double Puddling Furnace.

the hearth basin are also formed of lumps of iron oxide, fused together by the heat of the furnace. Hoop iron is burned to an oxide over this mass to give it an even surface of pure oxide.

The materials of which the hearth and its sides are prepared are designated as the *fettling* of the furnace. They are gradually consumed as a part of the operation of the furnace and must be renewed occasionally.

The hearth materials are kept from melting during the operation of the furnace by the radiation of heat from the plates on which it is built.

108. Puddling-Furnace Operation.—Having prepared the hearth and brought the furnace to a good heat, a charge of about 1500 lbs. of pig iron is thrown in at the working door, and with it is charged a quantity of cinder or squeezer scale.

(1) The door is closed tightly, and the heat is so regulated that the iron and the cinder become pasty and melt down together. This requires about 30 minutes, and is called the *melting-down stage.*

(2) After the charge has been melted and the iron and cinder well mixed, the *clearing* stage follows. The puddler's helper uses an iron bar with a bent end to stir the whole charge thoroughly, working through the hole in the door. The stirring brings the impurities of the iron into contact with the oxides of the hearth and of the charge, and these, assisted by any oxygen coming from the air which enters through the fire box, oxidize the remaining silicon, manganese, and a further amount of the phosphorus. During this stage, the furnace is kept very hot. A slag is formed, containing the oxidized impurities and much iron oxide.

(3) The next step is the *boil,* from which this whole process gets its name of "pig boiling." This lasts about 30 minutes and the operation removes carbon and the remainder of the phosphorus. During this stage the chimney damper is lowered and the working door opened to reduce combustion and produce an oxidizing flame. The charge is stirred thoroughly and constantly with the hoe or rabble (or, to use the expression of puddling, is rabbled). This vigorous action brings the carbon of the metal in contact with the iron oxides of the hearth and the charge, causing carbon and oxygen to unite, forming CO, which bubbles violently from the surface of the molten charge. This bubbling causes the lighter slag to boil over the side of the basin and flow from the furnace, carrying with it many of the oxidized impurities. Sulphur is eliminated mostly as iron pyrites in the slag boil. As the carbon burns out, the charge becomes more and more quiet.

This removal of the carbon having lowered greatly the melting temperature of the iron, small masses of plastic metal begin to

collect just as butter collects in the churn. The iron is said to "come to nature" in thus collecting.

(4) In the *final* stage, the puddler gathers these masses into balls of about 150 lbs. each, called *blooms,* or *puddle balls.* The furnace temperature is gradually raised, and the puddle balls are brought to a welding heat. The puddler presses them sufficiently to make them hold together and they are then removed from the furnace. After their removal the excess of slag is tapped out and the furnace is ready for a new charge.

Each heat requires about 2 or 2½ hours.

109. Treatment of Puddle Balls.—The furnace treatment just described burns out almost all of the usual impurities in iron, but

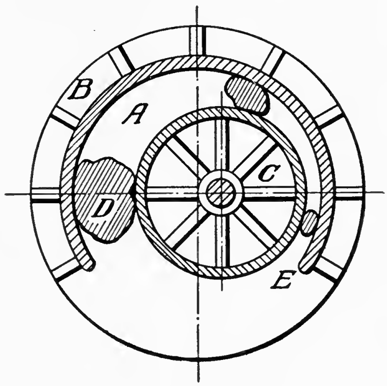


FIG. 19.

this treatment produces a slag or cinder of iron oxide and silica which mixes with the iron and forms a sheath around each iron crystal.

When the puddler has formed a ball for removal from the furnace, his helper takes it out by means of a pair of heavy tongs suspended from an overhead trolley, and pushes it over to the squeezer.

This machine (Fig. 19) consists of a heavy cast-iron casing *B,* within which revolves a rough-surfaced cast-iron cylinder *C.* The space *A* between the cylinder and the casing is wide at one opening and somewhat narrower at the other. The cylinder is constantly revolving slowly, and when the puddle ball starts at *D,* it is rolled and squeezed until it emerges at *E.* This operation presses out

masses of cinder with more or less violence and noise. Fig. 20 shows a squeezer for heavy work.

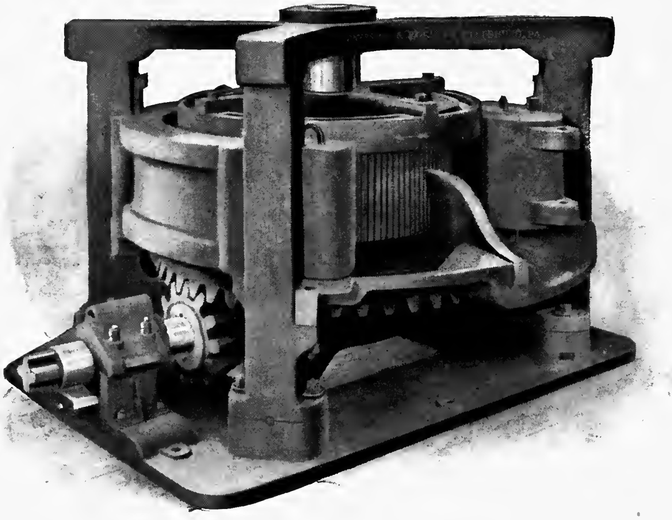


FIG. 20.—Squeezer for 400-lb. Bloom.

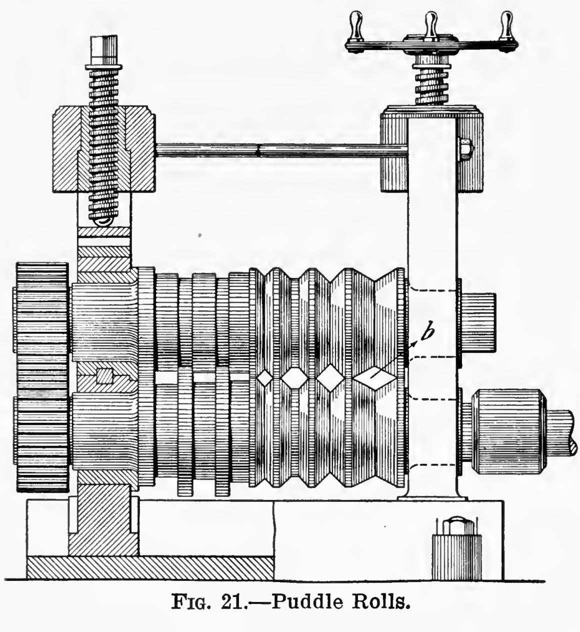


FIG. 21.—Puddle Rolls.

The bloom emerging at *E,* Fig. 19, still at a high heat, is immediately grasped with heavy tongs and started through the rolls shown in Fig. 21. The end of the bloom is presented first to the largest pass, *b,* and when it has gone through this pass, it is sent back over the top of the upper roll and is in turn run through the entire seven passes. Some cinder is pressed out, and the iron particles are pressed into a more tenacious mass. The last pass, which is near the center of the rolls, leaves the bar about 6 inches wide and less than an inch thick.

This product is known as *muck bar* or *puddled bar.* The rolls have elongated the iron crystals, giving the bar a fibrous structure, and each fiber is enclosed in a thin sheath of cinder, with streaks of cinder between many of the fibers.

110. Re-heating and Welding Muck Bar into Wrought Iron.— Muck bar still contains too much cinder and is too lacking in homogeneity for use.

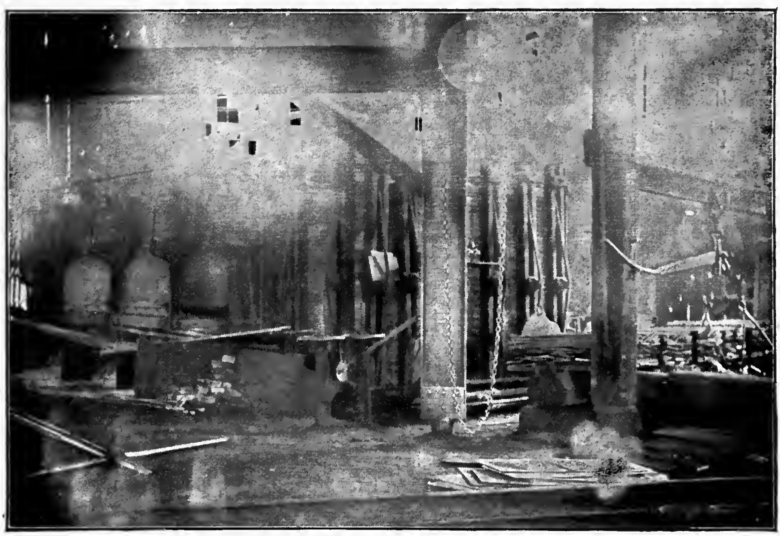


FIG. 22.—Re-heating Furnace used in Making Wrought Iron.

When cold, it is cut into lengths of about $3\frac{1}{2}$ feet. Bundles measuring about 20 inches wide by 20 inches high are then made up of muck-bar lengths and wrought-iron scrap. Each bundle, called a pile, is held together by a wrapping of heavy wire or thin

iron bands. A number of these piles are shown on the right in Fig. 22, ready for wrapping. These piles are placed in a re-heating furnace of the general type shown in Fig. 22, heated about three hours until they reach welding heat and are then taken out one at a time, and quickly passed through heavy rolls adjacent to the furnace.

A few passes back and forth through these rolls, called the *roughing rolls,* squeeze out a great amount of the remaining slag with much explosion and noise and thoroughly weld together the several pieces composing the pile. The rolls then work the mass down to approximate shape as plates or bars and it is then conveyed along the roller table to the finishing rolls by which it is shaped into sheets, bars, or rods as may be required.

For rapidity and economy of handling piles there are several re-heating furnaces and at least one set of roughing rolls placed along the arc of a circle, at the center of which is a heavy electrically operated crane so mounted with a horizontal arm that piles may be transferred from the furnaces to the roller table with a minimum loss of time.

111. Rolls for Shaping Wrought Iron.—Fig. 23 shows the general type of rolls used for wrought-iron piles. This machine is very simple, and consists essentially of three chilled cast-iron rolls *A, B, C,* mounted in a frame *DD* (called the housings) so that the axes of the rolls are horizontal and one above another. Rolls *A* and *C* are driven by a large engine through the connecting shafts *G* and *H,* and the middle roll is free. The bearings of the lower roll are fixed in the housings of the machine, the bearings of the middle roll are free to raise or lower, and those of the upper roll are raised or lowered by long screw rods worked simultaneously by the gearing on top of the machine. In this way the space between the rolls is adjusted readily by the operator to suit the thickness to which the iron is to be reduced as it passes through.

The mass of iron which passes back and forth through these rolls is handled by a roller table on each side of the machine. The roller table on one side is shown in the foreground. Its rollers are connected by gearing (not shown) so that all rollers may be made to revolve in either direction simultaneously. As the table now rests, it shows a plate *L* which has just come through between the middle

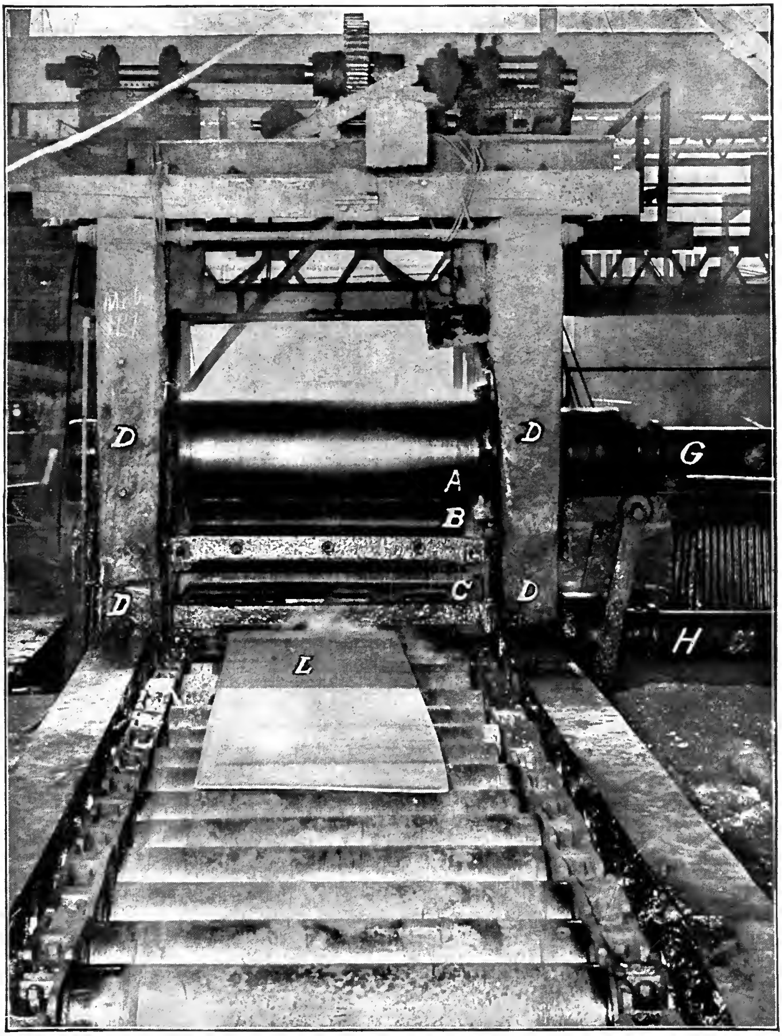


FIG. 23.—Rolls for Making Wrought Iron Plates.

and lower rolls. In order to run this plate back between the middle and upper rolls, the end of the table is lifted by hydraulic power. The table end having been lifted to the required height, its rollers are reversed and the plate is conveyed into the rolls of the machine.

Roughing and finishing rolls are of similar construction, but the former is a heavier machine than the latter. Most the shaping is done in the roughing rolls to save the smoother surface of the finishing rolls for the more careful work they have to do in finishing plates to a smooth surface and to uniform thickness.

A machine for rolling bars or rods has passes in the rolls similar to those in the puddle rolls in Fig. 21.

When material has been rolled to the shape and size required, it is carried by the roller table to another part of the shop where it is inspected for defects, and is then cut by the power shears to the required dimensions.

IV. The Manufacture of Steel.

112. History of Steel.—The first known steel was possibly produced accidentally by the primitive method which smelted wrought iron direct from the ore. The increase of the degree of heat in the primitive smelting furnace caused the iron to become hot enough to absorb in a combined form that quantity of carbon which gave it a new property. It was found that, although this newly discovered grade of metal had to a greater or less degree the malleability of wrought iron when cooled slowly, it further had the property of becoming hard and brittle when cooled suddenly from a red heat.

The uses of steel made in this primitive way must have been very limited because of the uncertain means of producing it.

Not until the *cementation* process of steel making was discovered and developed, about 1770, did steel become a fairly dependable and practical product, although its uses remained confined for a long time, by the limitations of this process, to the making of cutlery, edged tools, and special parts of machinery. The cementation process could not supply steel for a wider field of use because (1) the product in large quantities lacked uniform composition; (2) it could not always be depended upon when strength was of first importance, and (3) its production was expensive.

The need for a steel of uniform quality, dependable strength, and low cost in large quantities, led to investigations along other lines of possibility in steel production. The puddling process, as used in wrought-iron making, was tried for steel making, with the idea that the burning out of carbon should be stopped when enough remained in the charge to give the grade of steel desired, but this was not satisfactory because the stopping of the oxidizing process at the point to retain the necessary amount of carbon left too much of the other impurities in the metal.

Finally, in 1856, Sir Henry Bessemer made public the process which bears his name. In 1868 Sir Wm. Siemens in England and Messrs. Martin in France perfected the Siemens and the Siemens-Martin processes (almost identical) which are developed from the puddling process for wrought iron. These processes have revolutionized the manufacture of steel, and have so extended its limits in regard to its carbon content, that a new definition of the product became necessary, particularly as mild steel cannot be hardened by sudden cooling.

It was early discovered, in the use of these processes, that a reliable steel could not be made from pig iron containing more phosphorus or sulphur that the steel should contain, because these impurities do not remain oxidized in a furnace or converter with a silica lining, as then used, and therefore could not be disposed of with the slag. Silicious materials are acid materials, and they reduce oxidized phosphorus and sulphur as soon as it is formed, causing these impurities to re-enter the steel. The use of silica linings in the furnace and converter classed these processes as acid processes of making steel. This limitation of the newly discovered processes restricted them to the use of pig iron low in phosphorus and sulphur, and this restriction caused investigators to seek and develop the *basic* method of steel making. This method differs from the acid process primarily in having a lining of basic material for the furnace and converter. Such a lining permits the use of a lime flux, which will remove phosphorus and surphur, while a silica lining will not permit the use of a lime flux, because chemical action between lime and silica would soon disintegrate the furnace or converter lining.

113. The Cementation Process.—By this process, wrought-iron bars are converted into steel. Alternate layers of sifted wood charcoal and iron bars are placed in fire-brick basins or "pots," the tops of which are made air tight with a layer of clay. This prevents burning the charcoal. The pots are then heated in a large furnace. Maximum heat is reached in about 48 hours, and this is continued for 8 to 12 days. The fire is then allowed to die out and the bars are removed when cold.

The high temperature has caused the iron to absorb the carbon in sufficient quantity to change it into steel.

The product thus obtained is called *blister steel* because the bars are covered with blisters as a result of the process. This steel is not yet ready for use, as the carbon is very unequally distributed in it, making some spots very hard while the interior remains soft.

To correct this lack of homogeneity the blister steel is further treated by one of the two following-named processes:

(1) Cut or broken into small pieces, melted in covered crucibles, and poured into ingots suitable for rolling or forging to the shape desired. This equalizes the distribution of carbon and any other elements in the steel, gets rid of the slag or cinder which formed a part of the wrought iron, and makes a very superior grade of steel. This is known as *crucible steel.*

(2) Cut into suitable lengths, piled, welded and rolled as in the case of muck bar. This process helps to average up the distribution of carbon in the steel, particularly when several times repeated, but it does not make the steel homogeneous, as when melted in the crucible, and each repetition of heating and welding adds to the expense of the product. This product is known as *shear steel.*

The cementation process has practically passed into history, except that its use continues in some place in Europe, particularly in Sheffield, England, where it has been long in vogue, and much skill has been acquired in using it. Steel is there made by this process from the purest wrought iron for a superior grade of cutlery.

The crucible part of the process, however, is still retained, as will be outlined later on, and is an important branch of steel making.

114. Present Processes of Steel Making.—At present there are in extensive use three processes of steel making. These are, in order of the annual quantity of steel produced by each:

(1) The Bessemer process.

(2) The open-hearth process (Siemens and Siemens-Martin).

(3) The crucible process.

Each process is particularly adapted to removing the impurities from certain grades of iron, and also to producing certain grades of commercial steel. The Bessemer and open-hearth processes have made possible a low-carbon steel (mild steel) which finds extensive use as a structural material in buildings, bridges, hulls of vessels, steel rails, etc. This material is stronger and more uniform in quality than is wrought iron, which was formerly the only suitable material for these uses. The Bessemer process is the least expensive in operation, and the quality of its product depends upon the grade of pig iron used. It is, however, being gradually displaced by the open-hearth process because of the diminishing quantity of ores suitable for supplying pig of the required composition.

High-carbon steel, limited in use to tool making, springs, and for special needs in which extreme hardness is an important feature, is made by the crucible process. Of the three processes, the crucible process produces the highest grade and most expensive steel.

115. The Bessemer Process.—This process converts pig iron into steel by blowing cold air through the molten metal to burn out the carbon. After the carbon is removed (and incidentally some other impurities are removed), and the air blast stopped, enough carbon is re-introduced into the charge to give the steel the amount required.

This operation is carried on in a large vessel called a *converter,* a view of which, partly in cross section, is shown in Fig. 24. The shell of the converter, marked *D,* is built of steel plates in three sections, held together by brackets *E.* To the bottom is bolted two castings *J* and *K* which form a hollow receptacle called the blast box or wind box. Two other plates may be seen in the bottom, the upper serving to strengthen the bottom, and the lower, marked *L,* serving to hold the tuyeres *M* in place. The shell is lined for the acid process with ganister, and for the basic process (not used in

America) with magnesite, chromite or dolomite. The lining is marked *C*.

The vessel is supported by an encircling band *G*, which carries two trunnions *BB*, by means of which it can be tilted when neces-

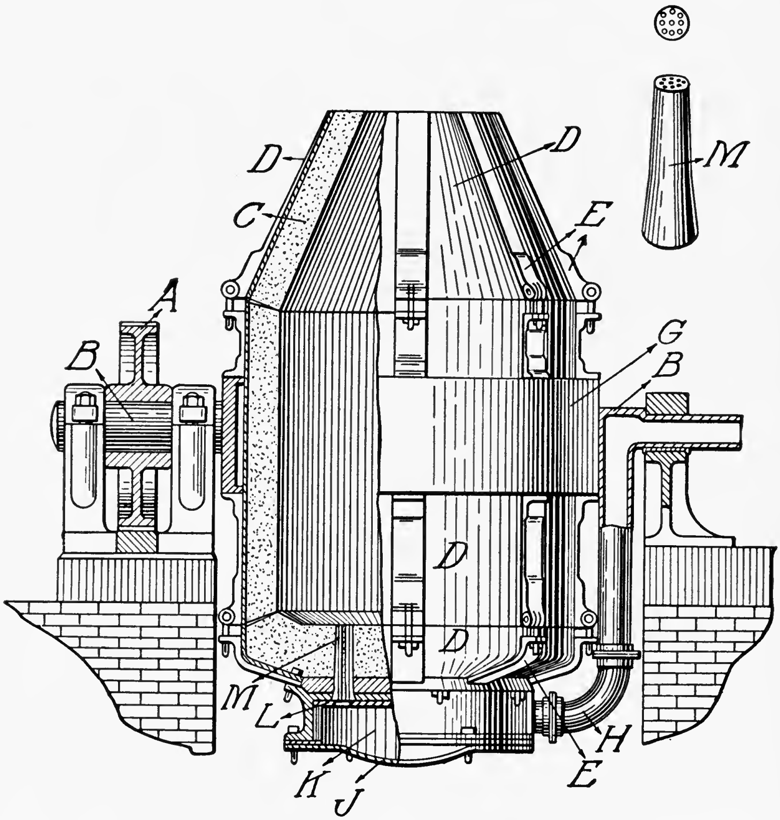


FIG. 24.—Bessemer Converter.

sary. One trunnion is solid, and carries a large-toothed wheel *A* to which is geared the rotating mechanism. The other trunnion is hollow to afford a means of conveying air to the blast box *K*, through the pipe *H*. The small sketch *M* at the side shows one of the tuyeres, made of refractory material, which conveys air from the box to the interior of the converter.

116. Operation of the Converter.—The essentials of operating an acid converter are here given. The operation for the basic method is but slightly different.

After the converter has been emptied of a charge, the vessel is revolved another quarter of a turn until it is upside down. In this position it rests for a moment to drain out the excess of slag, and another quarter revolution places the vessel horizontally. In this position it receives a new charge. Ten tons or more of metal are brought over from the mixer in a large ladle and poured into the converter. Cranes * and other lifting appliances handle the ladle and other movable equipment, and all the movements of the converter are managed by mechanical appliances, handled by an operator on a high platform at a safe distance from its heat. Metal poured into the mixer is always hot enough to remain fluid for an hour or more and it needs no re-heating when conveyed to the converter.

The converter, with its new charge, is now revolved to an upright position, and the air blast is turned on just as soon as the metal begins to reach the tuyeres, to prevent it flowing into the blast box. The air pressure is about 20 or 25 lbs. per square inch, sufficient to push through the molten metal.

The chemical part of the operation at once begins when the air enters the molten metal, and a yellow flame of burning impurities, accompanied by a profuse shower of sparks of burning iron, issues from the mouth of the converter. Silicon and iron are first attacked by the oxygen, and these form, when oxidized, a slag which tends to rise, but is kept more or less agitated and mixed with the charge. After the silicon is burned out, the carbon is next attacked, and the formation of carbonic oxide causes a violent bubbling of the charge, a stage known as the boil. The small quantity of manganese usually present is now oxidized, and passes into the slag.

After about 20 minutes, the flame from the mouth of the converter has about died out, indicating the complete oxidation of carbon, silicon and manganese. A continuation of the blast would ruin the charge of metal by filling it with iron oxide. The blow is

* Figs. 25 and 27 show cranes and appliances for handling large ladles. Each of these views shows a ladle suspended from the crane.

then stopped, but just before doing this, the converter is turned horizontal to prevent metal entering the tuyeres. Little, if any, of the sulphur and phosphorus originally in the iron are removed, because in the presence of the silicious lining these impurities cannot remain oxidized.

After the blow the charge consists of molten iron without carbon silicon or manganese, but it contains phosphorus, sulphur and iron oxide. Enough carbon must now be supplied to produce the kind of steel desired, also the iron oxide and gases mixed with the charge as a result of the blow must be removed, so far as can be done. These are accomplished by adding to the charge about 10% of ferro-manganese. This is melted in a small cupola near the converter, or may be thrown cold into the converter in small quantities. The quantity and composition of the ferro-manganese must be so adjusted that the carbon therein will give the converter contents just the needed amount, and the quantity of manganese must be sufficient to reduce the iron oxide and also consume the free oxygen absorbed in the charge, the oxide of manganese so formed rising into the slag. The slight agitation caused by these reactions helps to expel inert gases from the charge.

The stopping of the blow allows the charge to become quiet, and most of the slag and gases rise to the surface. After the ferro-manganese has been stirred in thoroughly (which must be done promptly, as the metal must not become chilled) the process is completed by tilting the converter and pouring its contents into a large ladle, previously heated inside by a charcoal fire or an oil flame. The greater part of the slag flows from the converter into the ladle and floats on the surface of the metal, affording it protection against oxidation and rapid cooling. Some slag sticks to the converter lining. This protects the lining, assists in the converter reactions of the next charge, and retains much heat.

117. Pouring the Steel into Moulds.—The ladle is at once conveyed by the crane to a row of large cast-iron ingot moulds, and the metal is poured, or "teemed," into them as shown in Fig. 25. Most large ladles are now poured from a hole in the bottom, but with ladles poured over the edge, care must be taken to skim away the slag to keep it from going into the mould. The slag is later poured

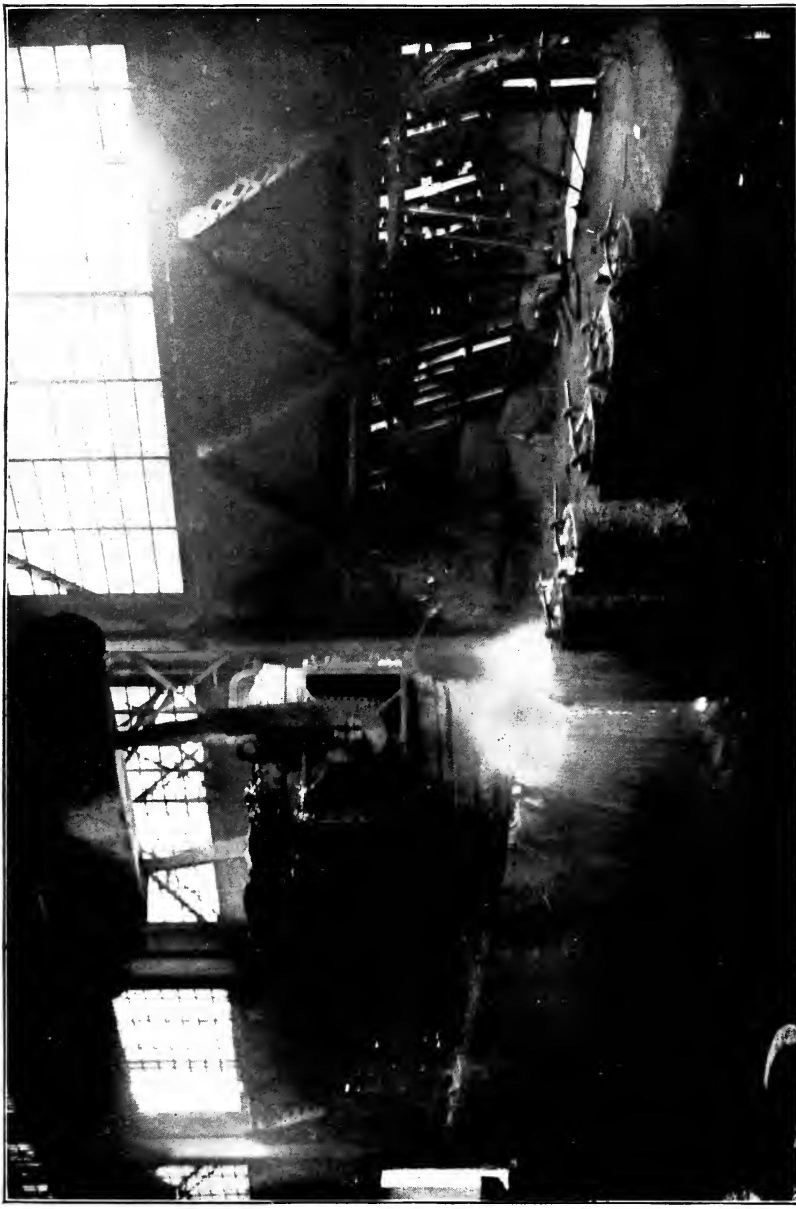


Fig. 25.—Pouring Steel into Ingot Moulds.

from the ladle into a steel-bodied slag car and conveyed to the dump. The crane moves the ladles readily along the row of moulds. In this view the moulds are filled through a clay-lined iron pipe, or "runner," leading into the bottom of each mould. These runners are, in this view, behind the moulds. The moulds are not lined nor are they previously heated, but ladles, pipes, troughs, and other refractory lined holders or conveyers of molten metal must be heated and must never contain any moisture when metal is poured into them.

The subsequent treatment of the ingots produced in these moulds is described in the next chapter.

118. Features of the Bessemer Process.—Pig iron of a certain range of composition must be selected for this process. It must not contain more phosphorus nor sulphur than is allowable in the steel, as these elements are not burned out in the acid Bessemer process. Silicon is desirable to increase the heat in the charge when it burns in the converter, and its is also the chief slag producer, although too much silicon would unduly prolong the blow while burning it out and this prolonged oxidation would consume much iron.

The converter charge is considerably increased in temperature by the oxidation from the blast and it may become at times so hot that the chemical reactions are upset, and much iron is consumed. To reduce the temperature, either a quantity of steel scrap of correct composition is thrown into the converter during the blow, or steam is forced through with the air, absorbing heat as it is decomposed in the charge.

Bessemer steel is not regarded as the equal of open-hearth or crucible steels in purity, as the removal of impurities is under better control in the two last-named processes. The Bessemer product is used for railroad rails, structural steel for buildings, steel castings, forgings, and other purposes where the strength of the steel is not put to its supreme test.

119. The Open-Hearth Process.—This and the Bessemer process convert pig iron into steel by first burning the impurities from the molten iron, but the equipment used in the open-hearth process differs considerably from that used in the Bessemer process.

The open-hearth process was developed along the lines of the puddling process for making wrought iron, and was made successful only after an improvement in the furnace used and after a modification of some of the steps in the puddling process. The two obstacles which had to be overcome in perfecting the open-hearth process were (1) supplying suitable fuel and burning it in such a way that higher temperature could be maintained than in the puddling furnace, and (2) building a furnace capable of resisting this high heat and serving the practical needs of the process. It was found that in burning out all the carbon and other impurities a much higher heat was necessary in order to maintain the purified iron in a molten state and not let it "come to nature" in a pasty condition, as in the puddling process.

To supply higher heat, the manufacture of producer gas was developed, and the principle of the regenerative stove, as used with the blast furnace, was applied to the steel furnace. A better furnace, to withstand the heat, was obtained principally by a careful selection of pure refractory materials and by a skillful mixing and burning of these into high-grade refractory bricks.

The open-hearth process includes both the Siemens process, which ures iron ore to assist in decarbonizing the pig iron, and the Martin process which melts scrap steel with pig to dilute the impurities in the latter. The combination of these two is the Siemens-Martin process, but their individual distinctions are now lost sight of as all their combinations are included in the one designation of open hearth.

The composition of available iron ores from different deposits of the earth renders necessary the use of both the acid and the basic methods in open-hearth steel making, and the control now possible of the various steps of this process, particularly in the removal of impurities, renders the product thoroughly reliable as a mild steel for high grade uses.

120. The Open-Hearth Furnace.—This is a reverberatory furnace to which is connected a regenerative system of heating. A longitudinal section of a furnace, lined for the basic process, is shown in Fig. 26, and the diagram below the furnace is a simplified arrangement to show plainly the connections and passages for air and fuel gas in the regenerative system.

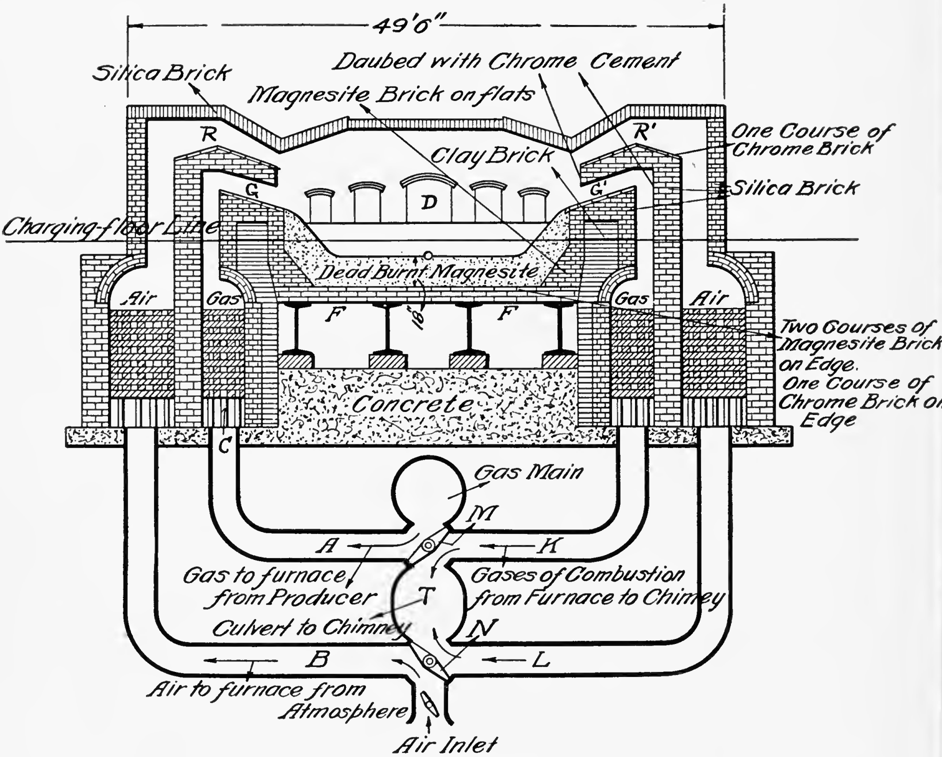


FIG. 26.—Open-Hearth Steel-Furnace.

The hearth or basin, built on flat steel plates *FF* which are supported by *I*-beams, is composed of brick and magnesite as shown. The charging doors *D* are on the side of the furnace next to the charging platform (about 12 feet above ground level) and the tapping hole is on the opposite side of the furnace. The roof of the furnace is made of silica bricks arched across the furnace.

The lower sides of the air ports *RR'* and the gas ports *GG'* are covered with a layer of chrome brick, a basic material, as these bricks may become loosened and fall into the metal in the hearth. Above the level of the molten charge, where no chemical reaction will result, the furnace is built of silica bricks to save expense of basic materials.

Opening into each end of the furnace are two ports (*R* and *G* on one side and *R′G′* on the other) which convey air and fuel gas into the space above the charge where they mix and the gas burns, causing a long flame of intense heat which sweeps across the length of the basin or hearth. The regenerative system operates as follows: A supply of producer or natural gas from the *gas main,* marked in the diagram, passes along the conduit *A,* through the highly heated checker-brick work in the gas regenerator *C,* and enters the furnace through the port *G.* Air drawn from the atmosphere passes through the *air* inlet, along the conduit *B,* through the checker-brick work of the air regenerator, and enters the furnace by its port *R.* Both gas and air are highly heated by passing through the incandescent checker-brick work of their respective regenerators, and as soon as they come into contact they unite in a flame of intense heat. The draft of the chimney causes the products of combustion to pass into the gas and air ports *G′* and *R′* at the opposite end of the furnace, through the two regenerators below (to which they give up much heat) and along the conduits *K* and *L* into the culvert *T* which leads into a tall chimney.

At intervals of about half an hour, the valves *M* and *N* are reversed, this causing a reversal of the path of air and gas through the furnace and regenerative systems. In this way the regenerators at the opposite ends of the furnace act alternately as heaters of gas and air as they pass to the furnace, and absorbers of heat from the burned gases after they leave the furnace. This system makes possible the maintenance of the high heat which the open-hearth process requires.

The hearth is so supported as to leave a large space underneath open to the air. This allows a radiation of heat and prevents overheating of the materials composing the hearth. The entire brick work of the furnace is rigidly braced by vertical steel beams joined above and below the brick work by tie rods as shown in Fig. 27.

121. Charging the Open-Hearth Furnace.—The capacity of the average open-hearth furnace is about 60 tons of metal.

Supposing the furnace to be at a moderate heat, ready for the charge, the tapping hole, which leads from the lowest part of the basin through the far side of the furnace, is stopped by ramming into it a quantity of magnesite from the outside.

The charge consists of pig iron, limestone, usually iron oxide, and steel scrap if any of this is available. A quantity of limestone, determined by experience, is first thrown in through the charging door. The pig iron is then brought molten in a large ladle from the mixer or directly from the blast furnace, and is transferred from the ladle to the furnace hearth by means of a portable refractory-lined trough. Sometimes solid pigs may be thrown in at the charging door, but this is not the best practice, as there is considerable saving of fuel and handling by using molten pig. A quantity of steel scrap is next thrown in if available, but scrap must not be used unless its composition is known to be suitable to the grade of steel to be made. Steel scrap of the proper composition is highly desirable, as its impurities have been greatly reduced in its manufacture. A small quantity of iron ore, low in sulphur and phosphorus, is added to the charge.

122. Operation of the Open-Hearth Furnace.—The purpose of this operation is to remove, so far as can be done by the process, the silicon, manganese, carbon, phosphorus and sulphur in the charge. The removal of sulphur is difficult and uncertain, phosphorus is removed only in the basic process, and the remaining ingredients are usually reduced below the quantities desired in the finished steel and are re-introduced at the end of the process.

The doors are tightly closed after charging and the heat is regulated to melt the whole charge gradually, requiring from 2 to 4 hours. The furnace temperature begins at once to rise, and the limestone ($CaCO_3$) begins to decompose, forming CaO and CO_2. The increase of heat soon causes the silicon, manganese and carbon to begin to oxidize. The oxygen for this purpose is supplied mainly from the iron ore in the charge, to a less extent from the CO_2 of the lime, and to a small extent from the air entering through the regenerators. As the charge becomes more and more fluid, the iron and scrap become mixed, distributing their impurities evenly throughout their combined mass. The lime (CaO) and iron oxide float to the surface of the molten iron and become fused, mixing with the slag which has begun to form from the oxidized silicon and manganese and from the earthy matter of the charge. The slag spreads out evenly over the bath of iron, protecting it from the oxidizing action of the flame.

Unlike puddling, no stirring or rabbling is done, though the bottom of the basin is raked over by a long iron bar inserted through the small openings in the charging doors to loosen any part of the charge which may have stuck to the hearth.

From the time the metal is thoroughly melted, samples are occasionally dipped from the bath by means of a small ladle with a long handle. These samples are cast in a small iron mould kept my the melter, and when cold, are taken from the mould and broken. The melter judges instantly by inspection of the fracture the amount of carbon and phosphorus contained, and regulates the process accordingly. Another practice, more reliable, is to take the sample, after it has been cast and cooled, to the laboratory nearby and determine the quantity of these elements by exact chemical methods, requiring 15 or 20 minutes.

As the silicon and manganese decrease in the metal, the oxidation of carbon increases, causing the charge to ' boil " as in wrought-iron making, due to the formation and escape of CO.

The melter watches the progress of the operation through peep holes in the furnace doors, protecting his eyes with dark-colored glasses. His experience enables him to regulate the furnace temperature to suit requirements. He must so reduce the temperature that carbon will be burned out last. If the carbon is burning too fast, it is necessary to "pig up" the charge by adding solid pig to increase the carbon and chill the bath. If phosphorus (the last element to be attacked) is going too fast, as compared with the carbon, as shown by the sampling, the consumption of carbon may be hastened by "oreing down," that is by adding iron to supply oxygen to consume the carbon. It is essential that an excess of iron oxide should not be added, particularly toward the end of the process, as an undue amount of iron oxide cannot be carried by the slag, and, at the end of the process, distributes itself throughout the steel, greatly impairing its quality.

Toward the last of the process when the heat is still intense, and the bath is comparatively quiet from the cessation of other chemical action, the phosphorus is removed by becoming oxidized and at once combining with lime to form a stable compound. This compound, phosphate of lime, enters the slag. The burning out of the carbon continues at varying rates throughout the entire operation,

and the last of it is not burned out until after the removal of the phosphorus.

When the carbon has been burned out, the purified metal has a higher melting point than before, and would "come to nature," or collect in plastic masses as in wrought-iron making were it not for the high heat of the furnace to keep it thoroughly fluid.

In making high-carbon steel it is the practice to stop the process when the carbon has burned out to just below the per cent desired in the steel, and the small quantity needed is introduced by re-carburizing as in the Bessemer process.

The elimination of sulphur is very irregular. It is safest to use iron for the charge which has a sulphur content below that allowable in the steel, but this is not always practicable. Some sulphur will unite with lime and enter the slag, if very fluid, a condition assisted by throwing into the furnace a quantity of fluor-spar. Manganese ore added to the charge causes the formation of manganese sulphide, which also enters the slag.

The melter judges by the appearances in the furnace and particularly by the sampling, when the heat is finished.

123. Tapping Out.—It requires from 6 to 9 hours to bring a charge to the condition for tapping out. In this condition the bath of slag-covered metal contains some iron oxide and more or less oxygen, carbon monoxide, or other gases absorbed during the process. These must be removed so far as can be done, and the metal must be re-carburized to give it the quantity of carbon needed to make the grade of steel desired. In the basic process the materials used to accomplish these results cannot be placed in the furnace in presence of the basic slag as they will reduce the phosphorus from the slag and cause it to re-enter the metal, therefore these materials are mixed with the metal after it is tapped from the furnace.

The best material for this use is ferro-manganese, as used in the Bessemer process. Calculation and experience determine the amounts of carbon and manganese needed for each furnace charge and the quantity of "ferro" necessary to give these amounts is heated and thrown into the metal as it flows into the ladle.

In some cases, the metal charge may be re-carburized by throwing pig iron into the furnace. Still another method of re-carburizing is to throw into the ladle the necessary quantity of pure coke or

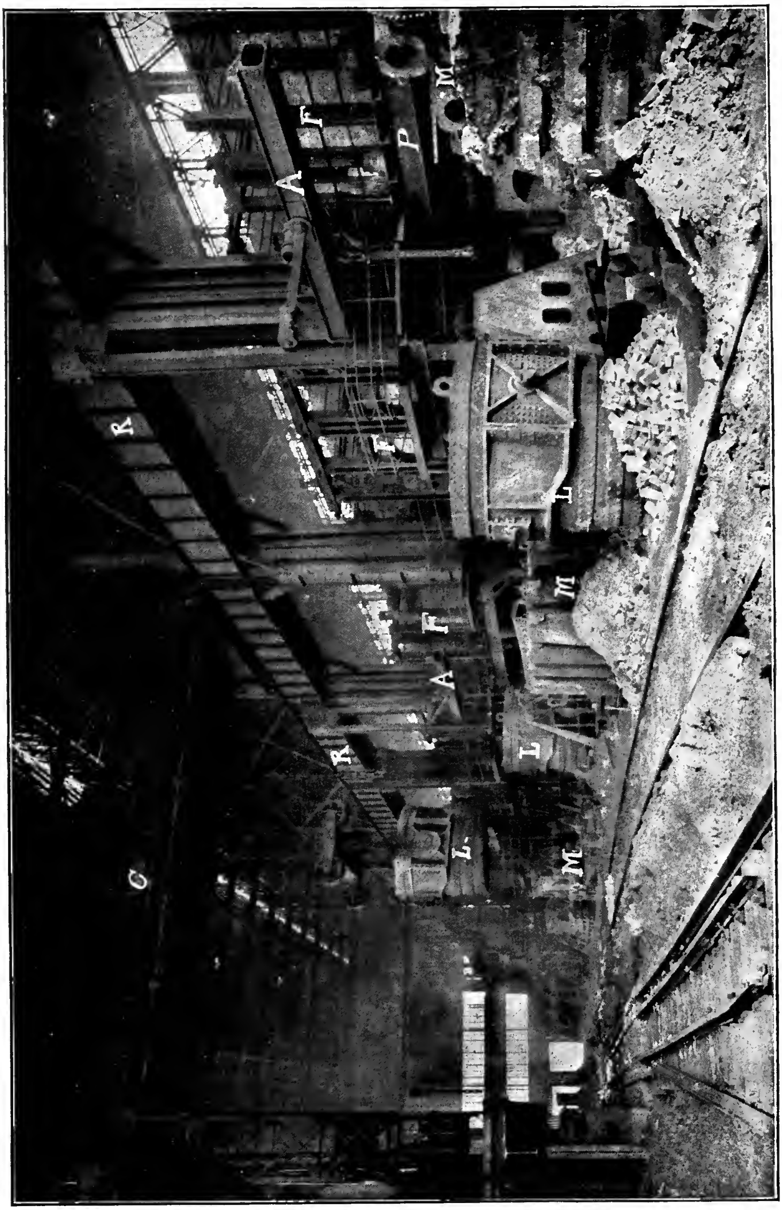


FIG. 27.—View along the "casting pit" of a set of Open-Hearth Furnaces. *F*, *F*, *F*, backs of furnaces above charging platform *P*; *C*, traveling crane; *A*, *A*, jib or swinging cranes; *R*, runway for one end of large crane; *L*, *L*, *L*, ladles; *M*, *M*, *M*, groups of ingot moulds.

coal ground fine and held in paper bags, or a better way of distributing this form of carbon is to allow it to run into the ladle, as the metal runs in, from a hopper suspended above the ladle. Considerable experience is needed in using powdered carbon, to introduce the correct quantity, as some of it burns before it can be absorbed by the steel.

The manganese in the re-carburizer decomposes iron oxide, takes up oxygen in the metal, forming MnO, which floats to the surface as slag. Its action assists mechanically in removing some of the other gases and some of the slag in the metal.

Preliminary to tapping out, a heated ladle large enough to receive the entire contents of the furnace is placed under the tapping spout. The view in Fig. 27 shows several large ladles along a casting pit adjacent to a row of iron-bound brick furnaces on the right. Fig. 28 shows the cross section of a large steel-cased ladle lined

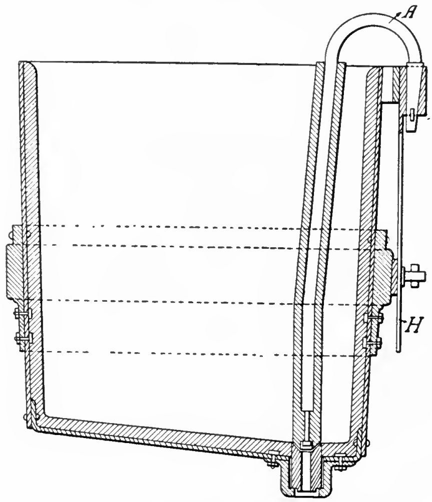


FIG. 28.—Bottom-Poured Steel Ladle.

with basic refractory material. This ladle is poured, or teemed, from the bottom as shown in Fig. 25. The bottom opening is controlled by a rod *A*, protected by refractory brick sleeves inside of the ladle. The rod is manipulated by the handle *H* held in suitable guides on the side of the shell.

A long steel bar is used to dig out the magnesite in the tapping hole. The metal flows into the ladle and nearly fills it. The slag flows from the furnace after the metal has flowed out, filling the ladle completely. Much of the slag runs over the edge of the ladle into a pit below, where it cools and is later lifted out by large hooks attached to the crane.

124. Pouring the Moulds.—When all the slag has flowed from the furnace, the crane lifts the ladle and carries it while the steel is teemed into the moulds, just as shown in Fig. 25. Small pieces of aluminum are thrown into each mould with the steel, reducing a part of any remaining iron oxide it may contain. The aluminum also assists further to remove gases, which would cause blowholes in the steel.

The ground space adjacent to the row of furnaces on the tapping side is called the "casting pit." A long narrow pit is usually dug for holding the tall moulds in order that the workmen may remain at the ground level when performing their work during pouring.

125. The Talbot Process.—This is a continuous open-hearth process, and seems destined to fill an important place in steel production. The furnace used embodies the same principle as the ordinary open-hearth furnace, but it is mounted on rockers so that any quantity of metal or slag may be poured out at will. Slag is poured from the charging side of the furnace and metal from the side opposite. When the charge is ready for tapping out, a part of the slag is first poured off and then only about one-third of the metal is poured out. That part of the charge which remains in the furnace is replenished with new stock to replace that poured out. In this way the process is continued from day to day, although it is necessary to empty the furnace about once a week for repairs to the hearth and the lining.

To the charge remaining in the furnace after each pour, there is added mill scale or ore, and limestone. These form a highly basic and a highly oxidizing slag, and when these materials are thoroughly fused, a quantity of molten pig iron is slowly poured into the furnace from the ladle. As this metal passes through the slag, a very vigorous reaction takes place between the iron oxide and the impurities in the metal, thus quickly burning out a large percentage of these impurities and thereby shortening the process.

The advantages of this process are as follows, viz.:

(1) A wider range is made possible in the grade of pig iron which can be used.

(2) The process is not dependent on steel scrap, which may be difficult to obtain.

(3) The wear and tear on the furnace hearth and lining are much reduced.

(4) A greater output of steel is obtained in a given time.

A tilting furnace, used in this process, has a capacity of 200 tons or slightly more.

126. The Duplex Process.—This is merely a combination of the Bessemer and open-hearth processes.

Pig metal is blown in an acid Bessemer converter until silicon, manganese, and part or all of the carbon are removed. It is then practically a molten steel high in phosphorus. From the converter it is conveyed to the basic open-hearth furnace for refining, for removal of the phosphorus, and for re-carburization.

The advantage claimed for this process is that it saves time, brings less wear and tear on the open-hearth furnace (which is the expensive furnace in steel making), and gives a better product than by the open-hearth process alone. It combines the acid process of the converter with the basic process of the furnace.

127. Uses of Open-Hearth Steel.—Open-hearth steel combines the two requisites of (1) a very reliable steel made in large quantities, and (2) moderate cost of production. Steel made by this process is used for bridge material, ship plates and frames, axles, tires, springs, wire, steel castings and tools not requiring extremely hard-cutting edges.

Armor plate, common projectiles, gun forgings and boiler material are made of open-hearth steel from selected materials especially treated to insure a minimum of phosphorus in the steel.

High-carbon steel can be made by the open-hearth process, but there is difficulty in eliminating sulphur and phosphorus. Because of this condition, high-carbon steel is made mostly by the crucible process, in which the impurities can be carefully regulated.

The amount of phosphorus in iron ore determines whether the acid or the basic process must be used in making steel from the iron smelted from this ore. The basic process is the one used to reduce phosphorus down to safe limits, but there is always the risk that phosphorus may by some accident get back from the slag into the steel before tapping out.

128. The Crucible Process.—The method of melting steel in crucibles or pots was brought into use as a means of improving the product of the cementation furnace, as mentioned in Par. 113. The introduction of the Bessemer and the open-hearth steel-making processes left very limited need for the product of the cementation furnace, but the method of purifying steel and iron scrap by melting it in the crucible gave a means of producing a higher quality of steel than could be supplied by other processes. The crucible melting feature of the cementation process was therefore retained and turned to excellent use. The expense of the crucible process (about three times that of the open-hearth process) would soon cause the disuse of crucible-made steel if the steel made by other processes could be substituted for it.

The ingredients in crucible steel can be regulated as desired, giving full control of the kind of product turned out, and making possible the manufacture of many alloy steels containing small quantities of unusual ingredients which would not bring dependable results by the Bessemer and open-hearth methods.

The crucible method is in many cases a method of steel refining rather than one of steel making.

The method of manufacture—melting in small pots containing about 100 lbs.—makes the crucible-steel output very small when compared with Bessemer and open-hearth outputs, and the product is disposed of entirely in making metal-cutting tools, wood-working tools, piano and other wires of high quality, highly tempered springs, armor-piercing projectiles and other steel articles demanding exceptional purity or hardness. Crucible steel is sometimes designated as cast steel, or crucible cast steel, because it may be cast into various shapes by pouring from the crucible into suitable moulds, and it is the first method by which steel castings were made.

129. Materials used in Crucible Steel.—Crucible steel is made principally from steel scrap, with which is combined cast iron if the carbon is to be increased, or muck bar if the carbon is to be lowered. All of these materials are of known chemical composition and are selected for their purity.

In the central space of the building devoted to this process is usually placed the set of crucible-steel furnaces, and along the walls on one or two sides are placed a number of bins not unlike horse stalls in a barn. In these bins are stored scraps or punchings of steel, pieces of muck bar, and chunks of pig iron, all cut or broken small enough to be readily packed in the crucibles. A highly important feature of these bins is that great care is taken not to let any metal be placed in them until samples are chemically analyzed and found suitable as crucible steel material; also each bin is reserved strictly for scrap of but one composition. It is essential that there be received no scrap which contains a greater per cent of sulphur or phosphorus than is admissible in the finished steel, because there is no practical way of removing these impurities in this process. It is a common saying in crucible-steel making that everything which goes into the pot comes out, meaning that none of the ingredients of the charge are lost by either an oxidizing or a reducing action of the furnace flame as in the other processes.

The materials for the highest grade of this steel are usually of Swedish or other iron exceptionally pure. These materials are in the forms of muck bar and pig iron mixed to give the per cent of carbon required in the finished steel. Wrought iron (muck bar) may be melted with enough charcoal in the pot to bring it up to the degree of carbon required, or cast iron may be mixed with a little good scrap to lower the carbon.

Other materials more or less needed in making up a crucible charge are (1) charcoal free from sulphur for carburizing the steel; (2) ferro-manganese for reducing any iron oxide in the scrap of the charge (usually stirred in just before the crucible is taken from the furnace); and (3) some form of silica (sand or ground silica brick) to act as a flux for taking up slag and oxides melted from the scrap.

130. Crucibles.—In America, crucibles are made of a mixture of half graphite and half fire clay, carefully kneaded, and moulded compactly by hand to shape as shown in Fig. 29. After they are

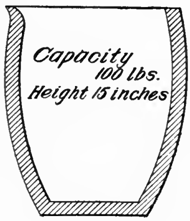


FIG. 29.

moulded, they are allowed to dry for several days or weeks, and those not cracked or distorted in drying are burned in a kiln.

The clay crucible is used in England, but is not so strong when hot nor so durable as the clay and graphite mixture. However, for low-carbon and alloy steels, a graphite crucible must have an inside lining of clay to keep the graphite from being absorbed by the molten steel.

A clay crucible lasts only through the two or three heats of a single day, while the graphite crucible, more expensive, lasts for ten or twelve heats and is not so easily broken in handling. The bottoms of discarded crucibles are sawed off to be used as lids for new crucibles.

131. The Crucible Furnace.—Modern crucible steel furnaces are heated with natural or producer gas by the regenerative system, though many coke-heated furnaces, similar to a brass-melting furnace, are still in use. Fig. 30 shows a vertical transverse section of a typical modern gas furnace for melting crucible steel. The greater part of the structure is in the regenerators, their walls and ports, while the furnace proper (the brick work surrounding the crucibles) occupies a comparatively small space. The regenerators have gas, air, and chimney connections as shown in Fig. 26 and need not be further described here. The top of the brick work is

covered with steel plates *A, A,* to form a suitable charging floor for the convenience of the furnace men. The structure contains usually four or more receptacles, *B,* which are the spaces for holding the crucibles and are commonly called the "melting holes." Each hole is large enough for six crucibles, and is covered with three movable lids, one of which is marked *C.* Linings of melting holes and of gas and air ports are so built of refractory brick that they may be easily renewed when worn out.

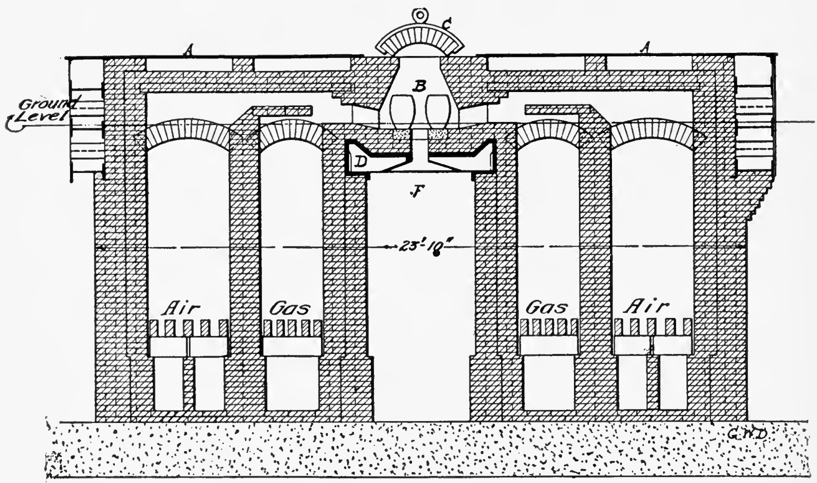


FIG. 30.—Crucible-Steel Furnace.

The several sets of melting holes are separated by thick fire-brick partitions. The bottom brick work of the melting holes and these partitions are supported by ribbed cast-iron plates, *D,* placed edge to edge over the vault *F,* which extends the entire length of the structure. Each melting hole has a 7-inch opening through the bottom to allow the steel to flow into the vault in case a crucible breaks. The vault *F* is kept closed at the ends while the furnace is in use.

Directly over the line of melting holes and enough above to allow ample head room, is a trolly bar equipped for lifting and lowering crucibles. The melting-hole covers are usually dragged aside and pushed in place again by an iron rod suitably made for this use.

Crucibles are lifted from or lowered into the furnace by means of tongs supported from the trolley bar.

132. Charging a Crucible.—A memorandum directing the superintendent of the crucible department to make a particular grade of steel gives him the analysis of what the steel must contain.

From the several bins are selected such materials in composition and quantity as will average up the composition required, and any special alloy material is introduced in the form of a compound. When each kind of material has been weighed out and piled by itself on the charging floor, enough crucibles are set out to hold the entire charge. Each crucible is packed cold with its proportion from each kind of material. Flux may be put in first or may be thrown in over the material when packed in. A little wet sand is plastered around the top edge of the crucible, the lid is put on, and the crucible is then lifted by the tongs, swung from the trolley bar and lowered into the furnace.

Crucibles just poured may be again lowered in the furnace and charged by aid of a funnel.

133. Operation of the Crucible Furnace.—After the regenerators have brought the furnace up to a high heat, the charged crucibles are lowered one by one into the melting holes. The chimney draft prevents flame from coming out of the melting-hole openings while the crucibles are being lowered in, but these openings should not be left open longer than absolutely necessary.

The path of the gases through the regenerators is changed about every 20 minutes to keep the crucibles from eating away on the hot side. In about an hour the melter looks into the pots to see if the melting has begun, using a pair of blue glasses framed in a small board to protect his eyes. His experience enables him to make such other inspections as will keep him in thorough touch with the progress of melting. In from 3 to 6 hours the charge is thoroughly melted. It is slightly stirred with an iron rod to lift any lumps of muck bar possibly at the bottom, and to mix the charge thoroughly. The seal of the lid on the crucible is broken by such inspections, but a new joint is soon made by the heat of the furnace.

After becoming molten, the temperature of the metal will increase, and soon the occluded gases begin to boil out. This step lasts about 20 minutes and is called "killing" or "melting to a

dead heat." It requires skill to determine when this has gone far enough. At the proper time, the crucible is lifted from the furnace and is set into a holder shown in Fig. 31 to be poured directly into a small mould, or into a hot ladle in which the contents of several crucibles are assembled if a large mould is to be poured.

If a crucible is taken from the furnace before the metal is "dead" it will pour "fiery," throwing off sparks and showing some agitation due to the escape of gasses, but if kept too long in the furnace, the metal will pour quietly, and the moulded ingots will be solid, but will be brittle and weak. The cause of this is uncertain, but is possibly to the absorption of an excess of silicon from the crucible walls at a very high heat.

In pouring from the crucible into the mould, which is washed inside with lime-wash to prevent the steel from sticking, great care

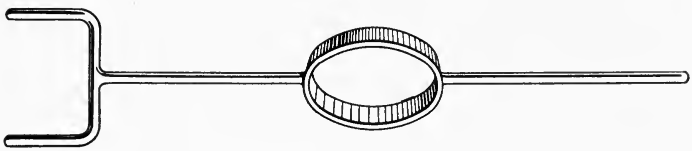


FIG. 31.—Ladle Shanks.

must be exercised to keep the metal from striking the side of the mould as this would chill a film of it and cause a lamination in the ingot.

It requires a large crucible plant, expert skill and quick handling to assemble enough crucible steel to make successfully a large casting. The Krupp works in Germany make crucible-steel ingots large enough for high-powered guns and armor plate.

134. Properties of Crucible Steel.—The reason for the superiority of crucible steel over steel of like composition from other processes is not always apparent, but is no doubt due in greater part to the following conditions, viz.:

(1) The stock is carefully selected, and has had the advantage of more or less refining by having been previously produced in a steel-making process.

(2) The covering of the crucible enables the elements of the charge to be better controlled in melting by avoiding losses due to the action of the flame.

(3) The melting of the charge distributes the carbon and other

elements equally throughout the mass, and sets free the slag and oxides which the scrap metals contained, allowing them to float to the surface.

(4) The boiling out of occluded gases before pouring gives a more compact steel.

(5) Before a crucible-steel billet is rolled, it is thoroughly hammered, while hot, under a steam hammer to make it compact and dense. This is called *tilting* because of the old method of hammering newly made iron under a tilting machine.

About the only important chemical changes are (1) the reducing of iron oxide by the introduction of ferro, when this is found necessary, and (2) the absorption of carbon by the metal. Incidentally the metal will absorb some manganese from the charge, silicon from the crucible walls, and sulphur and phosphorus from the slag, if these elements are present in the crucible.

135. Special Steels.—Iron will alloy with most metals, and some of these alloys have been highly developed for special purposes. These alloys are all alloys of steel and a small per cent of another metal. The metals most commonly used are nickel, chromium, manganese, vanadium, and tungsten, and investigations will possibly develop some surprising results from the use of other metals. Carbon is always present, but apparently as a secondary element.

These steels have several names, as "alloy" steel, "high-speed" steel, "self-hardening" steel and others assigned as commercial or trade names.

The advantages of these alloy steels are numerous, although these advantages are not embodied alike in all of the different compositions. Among the advantages are increased hardness, greater elastic and tensile strength, increased elongation before breaking, resistance to corrosion, and retention of hardness under the influence of high-friction heating. The most important uses for alloy steels are (1) for very hard cutting tools which can stand heavy machine cutting with but little wear, and (2) for high-grade rolled or forged structural material for use where minimum weight and maximum strength of material are required. Much alloy steel is now used in automobiles.

Nickel-steel has a very wide range of use for bridge material, ordnance forgings, wire cables, automobile parts, large axles, engine

shafts, and moving parts of marine and other high-grade engines. It contains from 1.5 to 4.5% of nickel, has a high elastic limit and the tensile strength is between 70,000 and 100,000 lbs. per square inch, according to treatment, while the best low-carbon boiler-plate ranges around 72,000 lbs. The presence of nickel in steel greatly retards corrosion.

Chromium has a more intense effect than nickel, in the same directions. Chrome steel is used for automobile axles and other forgings. Chromium is frequently combined in the alloy with nickel, and nickel-chrome steel is used for toothed wheels requiring great strength and resistance to wear, for very hard steel plates as in plows or burglar-proof safes, for jaws of rock crushers, and for armor and armor-piercing shells. Specimens of chrome steel shows an elastic strength of 180,000 lbs. and a tensile strength of 210,000 lbs.

Manganese steel possesses to a high degree the rare combination of extreme hardness and high ductility in one piece of metal. It is also non-magnetic. Its uses are restricted because cutting it to shape is extremely difficult. It may be forged, rolled hot, or cast, but any finishing of the shapes so produced must be done by grinding. It is used for burglar-proof safes, rails for curves on railways, jaws for rock crushers, etc. Castings of manganese steel may be battered badly out of shape without breaking, but they are too hard to be machined.

Self-hardening steel is so named because the steel hardens in the air upon cooling, and does not need to be plunged hot into oil or water as is the case in hardening carbon steel. *High-speed steel* is so named because when used for machine tools, it can cut metal at a very rapid rate without losing its hardness or without wearing away under the friction and resistance of cutting.

The hardest steel so far recorded contains .68% of carbon, 3.01% of chromium, 19.37% of tungsten, and .04% of silicon.

136. Ingot Moulds. Stripping Ingots.—The usual form of ingot mould for Bessemer and open-hearth steel is shown in Fig. 32, which shows three moulds sitting on a common base of heavy cast iron carried by an ingot car. Fig. 33 shows a longitudinal cross section of one of these moulds.

FIG. 32.—Ingot Car.

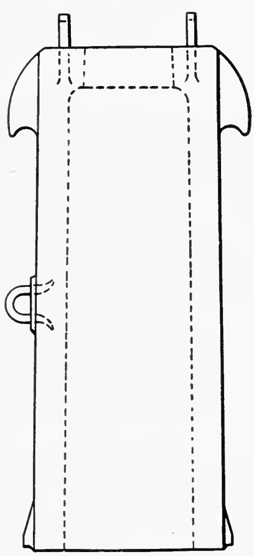


FIG. 33.—Mould for Steel Ingots.

The moulds are made of cast iron, are open top and bottom, and are provided with suitable lugs for handling. The mould cavity for standard moulds is $17\frac{1}{2}$ x $19\frac{3}{4}$ inches at the top, $20\frac{1}{2}$ x $22\frac{3}{4}$ at the bottom, and about 6 feet high, for a 6500-lb. ingot. It is slightly larger at the bottom than at the top to facilitate forcing the ingot out when it has become sufficiently cooled. The mould corners are rounded to avoid forming laminations which would result from square corners when rolling the ingot, and to relieve the ingot corners of a chilled and crystalline condition such as would result from the rapid cooling of sharp corners in the mould. The walls of the mould are about 5 inches thick, and the weight is suffi-

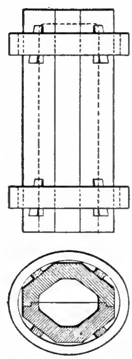


FIG. 34.—Crucible-Steel Billet Moulds.

cient to hold the mould down firmly on its base during the pouring of the steel. A fin of steel may run under the lower edge of the mould, but it is thin enough to chill very quickly and thus stop the opening.

The moulds shown are poured at the top, but for higher-grade steel, a mould is arranged with a long clay-lined tube up the side so that the metal may enter the mould space from the bottom.

For crucible steel, ingot moulds are much smaller and of different design from the larger moulds, although the shape of the ingot is nearly the same, *i. e.*, rounded corners, long, and sometimes tapering. For crucible steel, Fig. 34 shows two views of an ingot

mould made in halves, closed at the bottom and held together by iron rings and wedges.

The operation of "stripping" a large mould, *i. e.,* removing the ingot from it, is accomplished by a specially built traveling crane, such as shown in Fig. 35. A train of ingot cars is run under the crane and the crane-tongs *T* lift each mould by the heavy lugs at the top and if the ingot does not drop out, it is pressed out by a hydraulic plunger, *K,* rigged for this purpose.

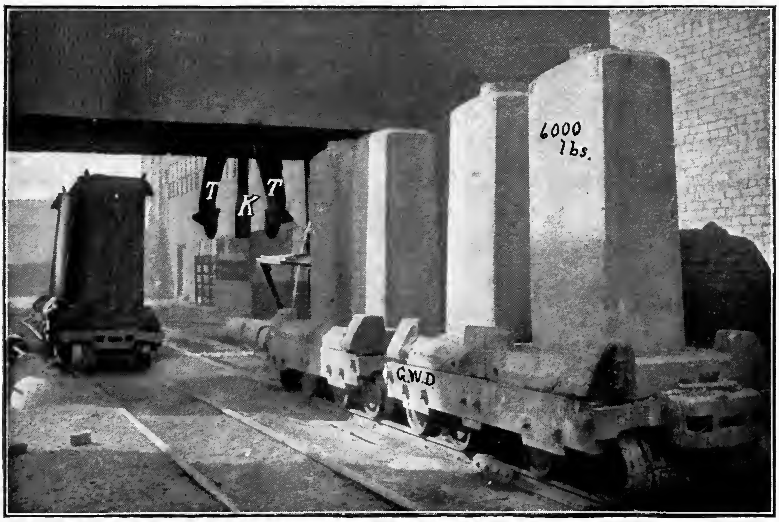


FIG. 35.—Ingot Stripper.

Four ingots stripped from the moulds are shown on the right in this view.

Ingots for armor plates, large gun parts, and other special forgings are cast in very large moulds, specially shaped and sometimes lined inside with clay. Some ingots are cast in long fluted columns for special advantages in cooling and working.

137. Impurities in Steel. Segregation.—Besides carbon, which determines hardness, steel contains a trace or more of manganese, silicon, phosphorus and sulphur, which came to it from the ore, or during the various stages of manufacture. Traces of other metals

also come from ores, but these are not frequent. In additin to these impurities, almost all steels contains some slag and oxides acquired during the molten state in the furnace, and more or less occluded gas acquired in furnace reactions or during pouring into ladle and moulds.

Skill and modern equipment in the manufacture of steel have made it possible to control in a great degree the *quantity* of impurities in the steel, but there is no way to control the *distribution* of these impurities throughout the mass of the ingot while it is cooling in the ingot mould. As the ingot cools, these impurities tend to go to the hottest part, which is the center of the mass. Through this tendency the metal is not uniform in composition and hence not uniform in strength and quality. This concentration of the impurities at the center of the ingot is known as *segregation*.

After steel is poured into the mould, and becomes quiet, there is an effort of the gases, slag, oxides, and of some other impurities to rise to the top, as most of them are lighter than the metal. After the ingot has cooled or after it has been re-heated to be rolled, a quantity of the impurities is eliminated by cutting off the upper end of the ingot before it is used. This is called the *discard* or *crop end,* and is frequently as much as 30% of the whole ingot. A discard of from 3 to 6% is frequently made from the bottom end of an ingot. Steel for uses not particularly requiring strength may have little or no discard cut from the ingot.

138. Defects in Steel Ingots.—Besides the presence of gas bubbles, and the result of segregation in a steel ingot, there are other defects which result from the pouring and cooling of the ingot in the mould.

A mass of molten metal naturally begins to cool at the surface, and as this chills, it forms a solid envelope about the molten mass in the interior. The contraction which results from cooling causes the metal to be drawn to the solid part as it cools, and in this way the central part of the ingot finally cools in a honey-combed state. The formation of the cavity at the center of the ingot is called *piping*. By the action of gravity on the molten metal this cavity is formed well toward the upper end of the ingot, and for this

reason, the ingot is always cast on end. The piping should be cut off in the discard.

Surface cracks will appear if the ingot is taken hot from the mould and exposed to air sufficiently cold to make this surface contract enough to disrupt. These cracks may ruin steel otherwise good, because in rolling the ingot, cracks simply close up but do not weld together, and in this way the material is more or less weakened.

In pouring, globules of steel are apt to splash against the sides of the mould and become chilled into shot. These fall into the molten metal but may not be wholly re-melted, particularly if they rest against the sides of the mould. When the ingot solidifies these shot are more or less separate from the metal surrounding them. These defects are called *cold-shuts.*

Also in pouring, a film of metal from the ladle may strike on the inside of the mould and become chilled, sticking to the mould. This forms a lamination, as molten metal rising in the mould does not entirely re-melt it.

139. Fluid Compressed Steel.—Many efforts have been made to improve open-hearth and Bessemer steels, with the view to having them approach crucible steel in quality without having its high cost of production.

One of the methods used for improving open-hearth steel is known as the Whitworth process of fluid compression. This consists of applying to a mass of molten steel which has been poured from the ladle into a suitably shaped mould, a pressure varying from 2500 to 4000 lbs. per square inch.

This process is of benefit because the reliability of steel is increased if (1) the density of the mass is increased, and (2) if the mass is made homogeneous, *i. e.,* the composition is the same throughout the mass. It is unlikely that this process increases the density of the steel itself, but it does decrease greatly the size of the gas bubbles in the steel, and compresses the particles of slag into compact masses. Piping is lessened but not prevented by this process, and possibly segregation is lessened. The steel under pressure is longer in solidifying, which gives the gas, slag, and oxides more time to rise into the discarded part of the ingot.

140. Compressing Steel.—The method of compressing steel is briefly as follows: On a specially built car not unlike an ingot car is placed a large cylindrical mould built up of very heavy cast-iron sections, one of which is shown in Fig. 36, bolted by their end flanges to each other and to a cast-iron bottom. For very heavy pressures, however, a steel tube forms the length of the mould, and this is fortified by a series of short steel tubes slipped over the long

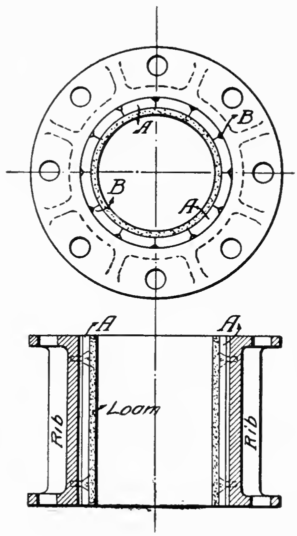


FIG. 36.—Mould Section for Whitworth Press.

tube, as shown in Fig. 37. The inside diameter of the mould is about 42 inches and its depth about 16 feet. The inside of the mould is lined with cast-iron bars as shown at *AA* in Fig. 36, plastered over with about ½ inch of loam, a refractory mixture of sand and clay. Two edges of each of the bars are champfered to form vertical openings, as at *BB,* by which air in the loam and some gases in the metal may escape.

The inside of the mould, having been thoroughly dried and heated very hot by a charcoal or oil fire, is poured nearly full of steel tapped from the furnace. The car is then run under a hydrau-

lic press (Fig. 37), the upper head *D* of which is stationary and carries a heavy plug *E* which will exactly fill the upper end of the open mould. The car having been correctly placed, the hydraulic ram *P* lifts the car body and the mould until the plug *E* is pressed to the intensity desired against the surface of the molten steel. A

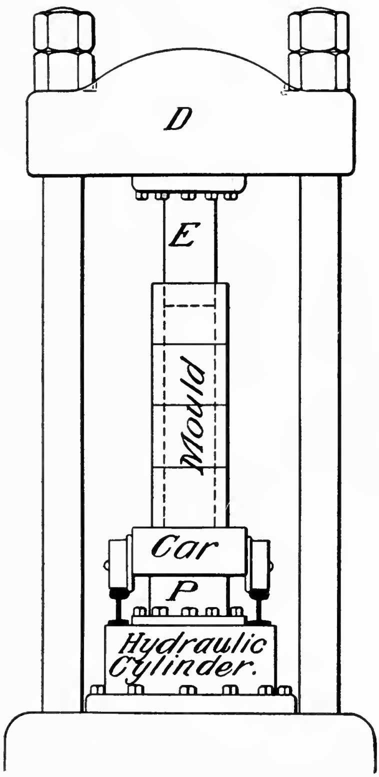


FIG. 37.—Whitworth Press for Molten Steel.

film of metal squeezes up between *E* and the mould lining, but it soon solidifies and prevents the escape of more metal. The pressure is held on the steel for about four hours, until the ingot has solidified. Some gas and slag are pressed out at the top and also from the surface of the metal in contact with the mould, but pressure cannot squeeze anything from the interior of the molten mass. However, it reduces the size of the bubbles and compresses the slag particles

densely together in the interior of the mass. An ingot fifteen feet long is decreased about 12 or 14 inches in length by this pressure. From 20 to 30% is cut from the top of this ingot, after it is cold, as a discard.

Steel of this kind is used for guns, armor, and marine-engine shafting. Its uses are not extensive because the expensive equipment for making it add to its cost and thus prevents a great demand for this steel in preference to other grades. The Whitworth process is not applied to Bessemer steel because open-hearth steel has the preference as a better product to begin with.

141. The Electric Refining Furnace.—Another method of improving the quality of steel, recently perfected, is that of electric refining. This method seems destined for a wide range of usefulness in steel making, as it does more than the Bessemer or open-hearth methods can do in eliminating initial impurities and in turning out a product freer from slag, oxides and gases. In fact the electric furnace promises to rival the crucible furnace in quality of product at lower cost.

The ability of the electric furnace to eliminate sulphur and phosphorus brings into the range of practical usefulness the enormous deposits of iron ores which have heretofore been excluded because none of the iron or steel-making processes could eliminate these impurities without undue cost. The success of this furnace is due (1) to the higher temperature which can be maintained and regulated as compared with the open-hearth furnace, and (2) to the control of the chemical reactions exclusively through the action of the slag which can be made of the right chemical composition for the reactions desired, and which forms over the metal a covering protecting it from the oxidizing or reducing action of atmospheric oxygen.

In the high temperature of the electric furnace, the chemical affinities of sulphur and phosphorus for iron can be overcome by certain elements placed in the slag, and by this means these impurities are reduced to within safe limits.

These furnaces will melt and refine the poorest grade of steel and iron scrap, but it is more economical to refine the steel preliminarily in the Bessemer converter or the open-hearth furnace and transfer it to the electric furnace for further purification.

CHAPTER V.

MECHANICAL TREATMENT OF METALS. HEAT TREATMENT OF METALS.

142. Forms of Newly Produced Metals.—The common metals are taken in a molten state from the furnaces which produce them and are cast into the forms outlined in this and the following paragraph. It must be mentioned that most of the pig iron produced by the smelting furnace is not cast into form as pig iron, but is converted into steel without leaving the molten state, and is cast as steel into ingots, billets and steel castings.

The courses followed by metals immediately after they are tapped from smelting furnaces are given in the appended table:

Metal.	How disposed of when tapped from the producing furnace.
Iron....	1. Conveyed in the molten state as hot metal or direct metal to the mixer or retaining reservoir which supplies the Bessemer converter and the open-hearth steel furnace; or conveyed directly to these without going to the mixer. Or, when tapped from the smelter is:
	2. Cast into pigs:
	(a) To be used in the foundry for making castings;
	(b) To be converted into wrought iron in the puddling furnace;
	(c) To be remelted for steel making as in item 1.
Copper..	3. Cast into:
	(a) Pigs or ingots (about 50 lbs.) to be remelted for brass and other alloys;
	(b) Billets for making seamless copper tubes and pipes;
	(c) Cakes for rolling into sheet copper;
	(d) Bars to be drawn into rods and wire.
Zinc....	4. Cast into slabs for subsequent uses.
Lead....	5. Cast into:
	(a) Pigs for remelting;
	(b) Cakes or slabs for rolling into sheets;
	(c) Bars for pressing through dies into wire and lead pipe.
Tin.....	6. Cast into blocks for remelting.

When steel is produced it is cast into:

(1) Ingots or billets for rolling into various forms of metal stock, or for making very large forgings.

(2) Steel castings of definite form for specific uses.

The uses of the words "ingot" and "billet" are somewhat confused. In steel making, ingots are large masses of steel usually about 20 x 20 inches in section and 5 or 6 feet long, but they may be smaller and even much larger and of various shapes of cross section for particular reasons. Small ingots, about 6 x 6 inches in section and smaller, are called billets. Billets may be formed either directly by casting steel into billet moulds, or by rolling red-hot ingots down to billet sizes. Billets are usually made in specified sizes as ordered by mills which manufacture them into a particular class of articles, as tubes, rods for wire drawing, tool steel, spring material, etc.

143. Primary Outline of the Shaping of Metals.—It will be seen from the preceding paragraph that all objects made of iron and steel may be divided into two general classes in regard to the methods of shaping them. These are:

(1) Objects poured from molten cast iron or molten steel, and known as castings.

(2) Objects shaped by mechanical pressure from hot-steel ingots and billets, or from wrought-iron "piles" bundled and heated for welding together.

Objects of the first-named class are cast usually in sand moulds made in more or less complicated shapes to produce a piece of metal for a particular purpose, as a steam-engine cylinder in cast iron or stern and stem posts of a ship in cast steel. Objects of this class are not hammered, rolled or otherwise changed in shape for final use except the finishing of them by more or less superficial cleaning, chipping, filing and machining.

As cast iron and steel castings are made in the iron and steel foundries respectively, which are subjects of another chapter, it is not intended to give them more than general mention here. It may be stated, however, that small steel castings are frequently made in steel works of steel directly from the converter, open-hearth or crucible furnaces; and that very large steel castings are necessarily made at steel works, where molten steel is produced in large quantities, rather than in the steel foundry, which is usually equipped for producing steel only in quantities of a few tons at a time. Large steel castings include such objects as rotor drums for steam turbines, rudder frames, stems and stem-posts for ships,

hydraulic cylinders, gun carriages, etc., which require a strength and elasticity not possessed by cast iron. These castings are made from low-carbon Bessemer or open-hearth steel.

The object of this chapter is mainly to outline the mechanical operations of the rolling mill and of the large forging press, both of which handle ingots of steel in their primary forms. The rolling mills converts ingots and billets into such well-known forms of metal as rods, bars, plates, railroad rails, and structural shapes used in bridge, ship and architectural construction. In these forms metals are supplied as stock to be re-manufactured into articles for mechanical, agricultural, domestic and many other uses.

Copper, brass, the bronzes and other metals are shaped into bars and sheets by rolling, and these metals, including the ductile grades of brass and bronze, are also shaped from their primary forms by the process of extruding, by which a solid mass of metal is forced hot or cold through a die of definite shape placed at the end of a steel cylinder which contains the metal.

144. Reducing an Ingot to Marketable Forms.—An ingot stripped from its mould should go while hot to the *soaking pit,* a large furnace in which it is placed to be brought to a red or yellow heat preparatory to rolling. From the soaking pit it is transported to the rolls, known specifically as the rolling mill, where it is passed several times back and forth between heavy rolls, the pressure of which reduces its cross-section size and at the same time greatly increases its length.

This reduction is known as *breaking down.* Ingots rolled square or nearly so in cross section and left larger than billets are called *blooms.* These are used for making large forgings, such as piston rods, crank shafts, connecting rods, etc., in engine-building works. Ingots rolled flat and wide are called *slabs.* An ingot rolled into blooms, billets or slabs is cut into suitable lengths for reheating and further working. Mills are now constructed which handle an ingot quickly enough to roll it into finished railroad rails, structural shapes, plates, billets, etc., without reheating; but rods, bars, and similar shapes of small cross section cannot be rolled directly from a large ingot because the metal gets too cold before it can be rolled so small, and the amount of material in an ingot would stretch out too long for practical handling in one piece of small section.

Steel blooms which come from the rolling mill must not be confused with wrought-iron blooms or puddle balls.

145. Reheating of Ingots. The Soaking Pit.—Although the stripped ingot may be at a glowing red heat as it comes from the mould, it cannot be rolled because the interior is yet liquid and the solid exterior would merely disrupt and allow the liquid interior to squirt out under the pressure of the rolls. The heat throughout the mass of the ingot must be nearly equalized in order that each part may be affected about alike under the rolls, although an ingot

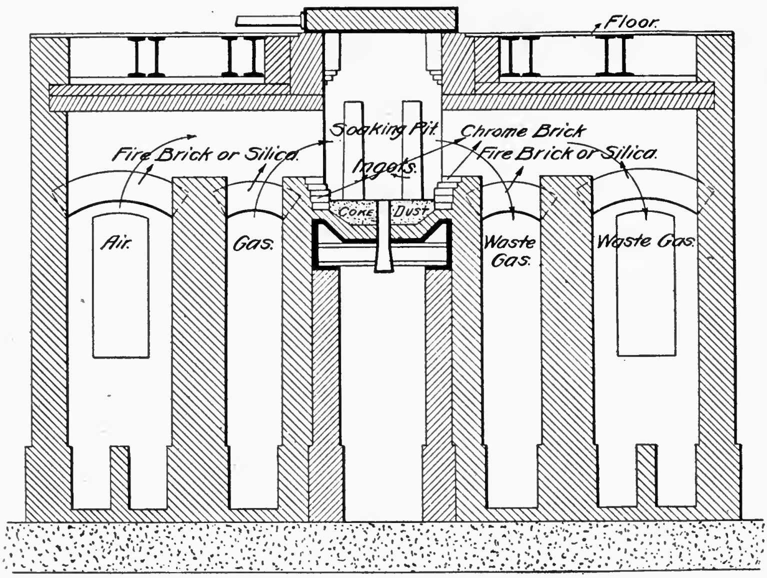


FIG. 38.—Soaking Pit for Steel Ingots.

rolls best when hotter at the center than on the surfaces. To equalize external and internal heat, *i. e.*, to stop the loss of heat from the exterior surface and allow it to become heated from the inside while, at the same time, the inside metal is solidifying, the ingot is placed in the soaking pit. The original soaking pit was merely a hole in dry ground lined with fire brick and provided with a thick fire-brick cover. The ingot radiated its heat to the walls of this pit and the non-conducting walls retained the heat until the ingot was of nearly equal temperature throughout.

It frequently happened that ingots became too cold before they

reached the pit, due to unavoidable delays, to be hot enough for rolling after they were "soaked." This condition necessitated some way of supplying external heat to the pits. The necessity of heating soaking-pits has gradually developed the soaking-pit shown in Fig. 38. This pit is heated by the regenerative system described with the open-hearth furnace.

As soon as ingots are stripped, they are hauled to the pits, weighed, lifted by a specially fitted crane and lowered into the pits. From

FIG. 39.—View over Tops of Soaking Pits.

6 to 8 ingots are placed in one pit, and they are kept in there, with the pit covered, for an hour or more, until they are at or above a bright red heat. No gas need be turned on if the ingot is stripped very hot, and mere "soaking" is all that is needed.

Fig. 39 shows a number of soaking pits. The crane is in the act of lowering an ingot into an open pit. The pit covers are slid horizontally by means of hydraulic cylinders, marked *C*, in the figure.

146. Rolling an Ingot.—When an ingot has reached the temperature for rolling, it is lifted from the pit and carried by the crane to the *ingot buggy,* where it rests until a lever is released to dump it on the *roller table.* The greater the reduction in size to be made in the ingot, the hotter it needs to be, because of the longer time required for rolling. It is best, when possible, to roll the ingot to the finished shape in a single heat, as a second heating adds to the cost of the finished materials. An ingot, for example, may be rolled into a length of five railroad rails of 33 feet each, making 165 feet in one piece, and this length could not be reheated without cutting it into pieces and much handling.

Fig. 40 shows the first stages in the process of rolling a large ingot. The mill in this view is known as a *reversible blooming mill.* This mill has too heavy rolls, the upper of which is shown at *R.* These rolls revolve in opposite directions and are driven by a large reversible engine or by a motor. The function of a blooming mill is usually merely to reduce the cross section of the ingot to a convenient size for finishing in smaller rolls to the exact cross section desired. The ingot *A* rests on the ingot buggy *B,* awaiting the breaking down of the ingot *C.*

The roller table consists of a succession of horizontal rollers *TT* driven in unison by the cogged bevel wheels *DD* from a single shaft running the length of the table. This table extends out from both sides of the mill, and conveys the ingot back and forth into contact with the mill rolls, which engage it and send it through, reducing its vertical dimension a given amount at each pass. When the ingot has passed through the rolls, it is turned on its side by a device called the *manipulator.* The motion of the table rollers and of the mill rolls is then reversed, and the ingot passes back between the rolls. After each pass, the upper roll, *R,* is let down a given amount by heavy screws which control its ends in the mill housings, and which are operated by the mechanism seen on top of the mill, under control of the man in charge. The roller table is driven by a reversible motor *G.*

After a few passes through the rolls, the ingot—or bloom, as it may now be called—is conveyed along the roller table to a heavy hydraulic-shearing machine which cuts off the discard from the bloom. The hydraulic shears are so mounted that the roller table

conveys material to and from them in the same way that it is conveyed to the rolls, and these shears are powerful enough to do their work instantly, without loss of time.

After the crop ends are sheared off, the bloom, still red hot, is conveyed back to the mill. Its passage back and forth between the rolls is repeated, and it is shifted by the manipulator from side to side of the roller table to direct it into the different sections or

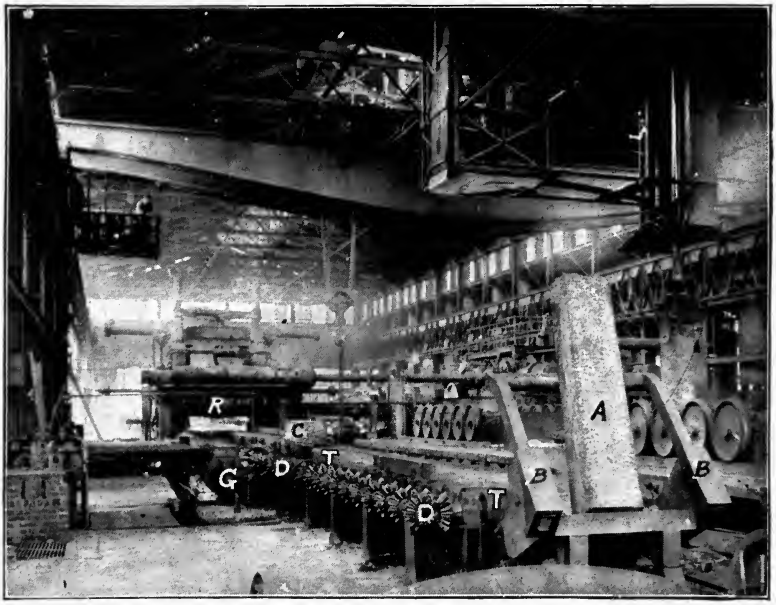


Fig. 40.—Starting an Ingot through the Blooming Rolls.

passes along the rolls until it is reduced to the size desired. It is then either cut into bloom length of 6 feet, more or less, by the hydraulic shears, or is conveyed by the roller table to another mill which rolls it in one length into railroad rails or other shapes of about the same cross-sectional area. However, a blooming mill may be fitted with rolls not only to do the work of breaking ingots down into blooms, but to do certain classes of finishing, as in rolling large billets or large structural shapes.

Throughout the rolling, the material is at a red heat.

147. Mill Scale.—In heating an ingot in the pit, particularly in an oxidizing flame, and in exposing the red-hot ingot to contact with the atmosphere, a film of iron oxide forms over its surface. This oxide is very brittle, and as soon as the ingot goes through the rolls, it drops off and falls through under the mill. This is known as *mill scale* or *roll scale,* and is valuable for use in wrought iron and steel furnaces, as has been mentioned.

148. Structural Steel Shapes.—The use of mild steel for structural purposes, *i. e.,* bridge building, ship building, architectural structures, railroad and other rails, etc., has developed certain standard shapes especially for these needs. The object sought in any structure built for strength is to dispose of the structural material in such a way as to get maximum strength for minimum

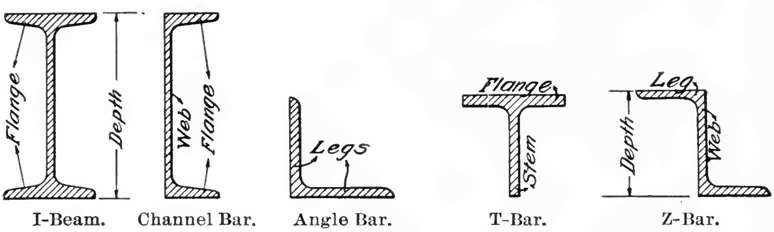


FIG. 41.—Structural Shapes.

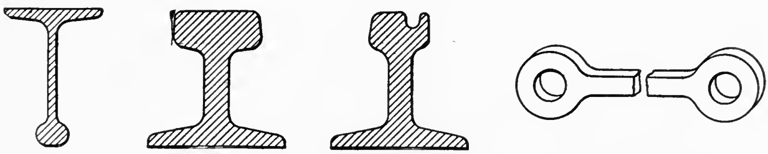
weight of material. This does not mean that in a structure the least possible amount of material must be used, but it means that the required safe strength having been determined, the material must be so disposed that a minimum weight of material will suffice to give this strength.

To carry out this principle, various shapes in mild steel have been standardized, but these shapes are not necessarily ideal, and are subject to improvement under experimentation. These shapes are shown in cross section in Fig. 41.

The cross-section form of each size of these shapes is standardized in area, thickness, length, slope and curvature of each part, and each running foot of length must weigh a given amount. Standard shapes of similar section are made of different weights per running foot. Special shapes are often rolled for particular uses or for a

particular class of uses, and are practically standards too, inasmuch as they are extensively used.

Other shapes, for special uses are shown in Fig. 42.



Bulb Beam. For Decks. | Railroad Rail. | * Trolley Rail. | Tie Rod or Eye Bar For Bridge and Truss Work.

FIG. 42.—Special Shapes.

Large steel mills issue an elaborate hand-book giving much valuable information of sizes, dimensions, weight, strength and other particulars of steel shapes.

149. Types of Rolling Mills.—The number of rolled products now common in the iron and steel trade, consisting of blooms, billets, structural shapes, plates, rails, bars, rods, etc., necessitates rolling mills of a variety of types and sizes for their production.

The largest mills, known as blooming, cogging and slabbing mills, roll ingots into blooms, slabs, or large billets. Some of these mills, as Fig. 44, have roll passes for rolling the larger structural shapes immediately after other passes of the rolls have broken the ingot down into a bloom of the required size. This saves much expense in reheating. Figs. 40, 43 and 44 are examples of the largest mills.

Mills next in size are in greater variety because of the greater diversity of products rolled by them. They receive blooms, slabs, and billets from the heavier mills, and roll them into a variety of forms such as small billets, structural shapes, railroad rails, sheet bars and plates.

The small type of mills, known as merchant and sheet mills, receive sheet bars and small billets from the second group of mills. Merchant mills roll billets into small rods and bars of a great variety of sizes and cross-sections, known as merchant bar and familiarly seen as stock in the blacksmith shop. Sheet mills roll sheet bars into thin sheets commonly seen as sheet iron.

* The thumb projection on this rail projects horizontally when rolled. The last pass through the rolls bends it up as shown.

Besides the foregoing classification of mills according to size and work they do, they are also classified according to design as follows:

(1) The *reversible mill* is one in which the two rolls are reversible and the material rolled is fed between them alternately from opposite sides of the mill. Figs. 40, 43, and 44 are examples of this class.

(2) The *three-high mill* is one with three rolls, which are not reversed. Fig. 45 is an example of this class.

(3) The *universal mill* is one which is provided with a pair of vertical rolls in addition to a pair of horizontal rolls. These four rolls press on all sides of a square piece of material as it passes through the mill. Figs. 40 and 44 are examples.

(4) The *pull-over mill* is a small two-roll mill which is not reversible. This mill is used for rolling thin sheet metals. When a slab passes between the rolls, it is pulled back over the top roll to be passed through again. A type of this mill is shown in Fig. 55.

(5) The *continuous mill* is a succession of small two-roll mills placed near together in line. They are used to roll merchant bar. In rolling small bars the metal loses its heat so rapidly that it is necessary to roll it quickly. The continuous mill accomplishes this by passing the material from one set of rolls to the next, and in this way a bar may be in the process of rolling between as many as ten pairs of rolls at once.

(6) The *looping mill* is another arrangement of several small two-roll mills to operate on small material quickly. These mills are placed edge to edge along a line and a red-hot rod a hundred or more feet long passes from the first mill in a U-shaped loop through the next, and so on through each successive mill in a snake-like curve until it is coiled up after passing through the last mill. This, material is used mostly for drawing into wire, which will be described later. As in the continuous mill, the material is passing through several pairs of rolls at the same time.

150. The Cogging Mill.—Fig. 43 shows a *cogging mill,* so named because its rolls are roughed or cogged to grip the end of the ingot firmly and force it into the rolls. The blooming mill in Fig. 40 does the same kind of work.

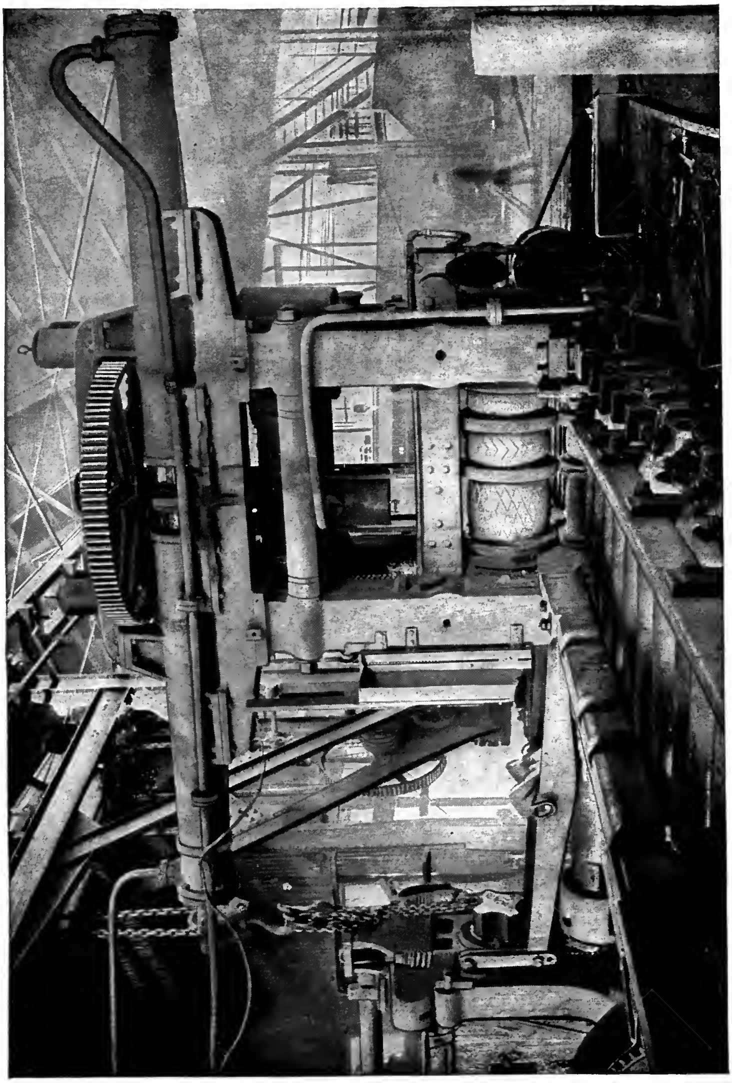


FIG. 43.—Reversible Blooming or Cogging Mill.

151. The Structural Mill.—Fig. 44 shows a *universal, reversible, structural mill.* This mill has two horizontal rolls *CC,* and two vertical rolls *DD.* The mill shown in this view is for rolling large *I*-beams, and the vertical rolls make the top and bottom flange surfaces parallel. The vertical rolls are run by beveled-gear wheels

FIG. 44.—Universal, Reversible, Structural Mill.

under the casing *K,* connected to the engine by the shaft *L.* They may be readily adjusted so that the distance between them is increased or decreased. The universal type of mill does its work more rapidly than is the case with other types of large mills. It is also much used in rolling plates to avoid the necessity of trimming the plate edges after rolling.

152. The Billet Mill.—Fig. 45 shows a *three-high billet mill.* Each of the rolls of this mill runs continuously in one direction as shown by the arrows. To allow a bloom (or a small ingot) to be run between the upper and middle rolls, this form of mill is equipped with lifting tables. A section of the roller table about 20 or 30 feet long which lies next to the mill on each side is so hinged that

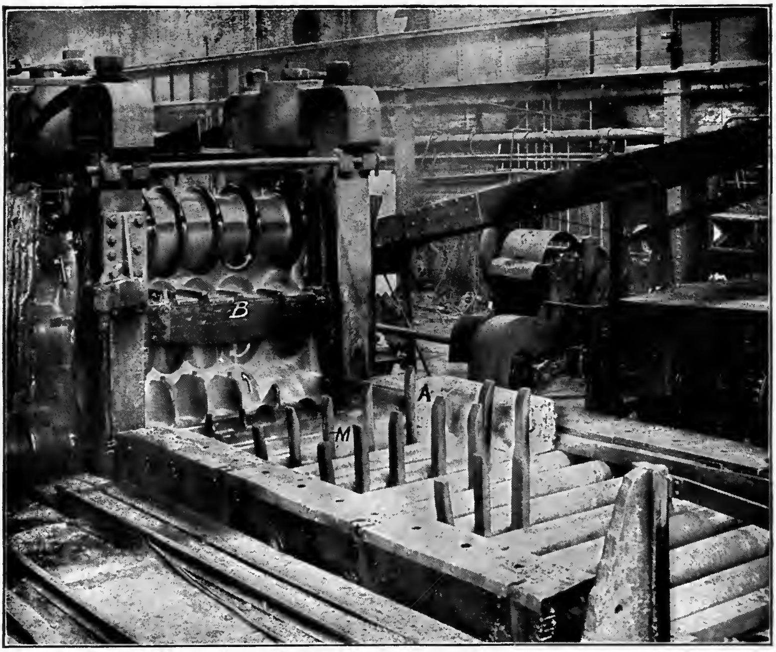


Fig. 45.—Three-High Billet Mill.

the ends adjacent to the mill can be lifted to the level B in the figure. After the bloom A passes through the mill with the table in the position now shown, the table ends on both sides of the mill are lifted by hydraulic mechanism. The table rollers are then reversed and the bloom passes back to this side. Both tables are then lowered to the position shown in the figure and the bloom is again passed between the middle and the lower rolls.

The rolls of this mill remain the same distance apart, and the bloom is reduced by being sent through the different passes between

the rolls, which are successively smaller along the rolls. The several fingers or prongs M are for the purpose of turning the bloom over and directing it to any pass through the rolls as may be desired. These fingers belong to the manipulator, various types of which are fitted to mills, and are so controlled by hydraulic mechanism that they can be lowered, raised and moved from side to side between the rollers at will.

153. The Rail Mill.—Fig. 46 shows the several mills for shaping railroad or street-car rails. These are three-high mills.

FIG. 46.—Rail Mill.

The blooming mill first breaks the ingot down to about 8 x 8 inches, the hydraulic shears cuts off the discard at the ends, and the ramainder of the bloom is then rolled by the mills shown in the view.

Quick handling and several mills are necessary to get the rail shaped before it loses its redness, as it is shaped completely without reheating. The bloom passes back and forth through one set of rolls

five times, is carried along the roller table to another set, which it passes through five times and then it passes once through the finishing rolls which merely smooth its surface.

These rolls are held the same distance apart throughout the entire operation, and the passes in them give the desired shape to the rail. When the ingot is rolled out into a rail it is something over 165 feet long—5 rails of 33 feet each. This length is sawed hot by steel circular saws, shown at S in Fig. 46, so that when each rail is cold it measures 33 feet in length.

154. The Sheet-Bar Mill.—Thin sheets of iron or steel are rolled hot from bars about 8 inches wide known as *sheet-bars.* The sheet bars for this industry are rolled in the *sheet-bar mill,* not unlike the billet mill in Fig. 45, and the method of rolling them from the ingot or from the wrought-iron "pile" is similar to that mentioned for rolling rails. The ingot is rolled out into a long strip 8 inches wide and varying from 3/8 to 1 1/8 inches thick. This strip is cut into lengths of 30 feet for convenience in handling, and is shipped to the *sheet mill,* the work of which is described in the next chapter.

The *skelp mill* is a special sheet-bar mill for rolling steel or wrought iron bars or "skelp" for the manufacture of iron pipe.

Plates of steel of 1/4-inch or less in thickness are designated as sheets.

155. Plate Mills.—Slabs from the blooming or slabbing mills are reheated and rolled by the *plate mill* into plates for many uses, including boiler plates, ship plates, tank plates, etc.

Plate rolling was described under the making of wrought iron. The largest plates now rolled are about 145 inches wide. The length depends upon the size of the ingot less the discarded ends.

In rolling plates, care must be taken to keep the upper surface of the plate free of mill scale, which would make a defective surface if rolled into the plate.

156. Names of Rolling-Mill Parts.—The more commonly designated rolling-mill parts include rolls, housings, roller table, manipulator, guides, guards, passes, and collars. Several of these parts have been mentioned.

Fig. 47 shows the outline of a pair of rolls with examples of typical passes between the rolls. *A* and *C* are *open passes, i. e.*, a fin of metal may be squeezed out from the sides of the billet if it

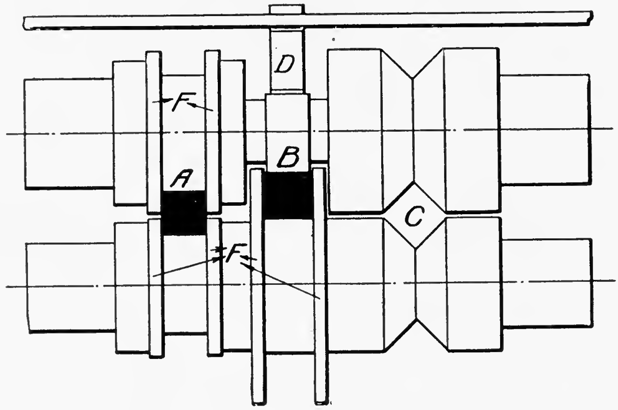


FIG 47.—Forms of Passes in Rolls.

is pressed hard enough. To avoid the forming of a side fin, the *closed pass B* is used. *F, F*, are *collars* on the rolls. *C* is called a *diamond* pass, and *D* is a bearing to support the upper roll because of its great reduction of diameter at the middle.

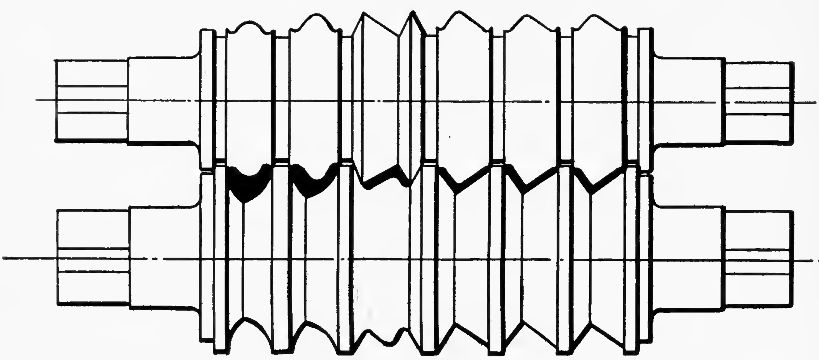


FIG. 48.—Example of Rolling an Angle Bar.

Fig. 48 shows six passes necessary for rolling a billet into angle bar of unequal legs. Successive changes in cross-section from the billet to the finished shape must be gradual, as here shown. The hot

material could not stand a radical change between successive shapes, as it would tear or distort. To avoid stretching one leg of the bar more than the other in rolling, the passes must be so made that the two ends of the legs will lie in a line parallel to the axis of the roll. Both rolls run at the same number of revolutions per minute, but the upper roll is slightly larger in diameter than the lower roll so that the rolled material will peel from the upper roll. To make the material peel from the lower roll when the first end passes through, a *guard* is fitted, as in Fig. 49. To prevent material from being engaged by the roll collars, and to direct it into the right passes, *guides* are fitted as shown in Fig. 49. Fig. 45 shows guides leading

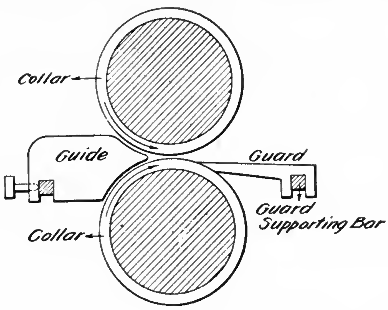


FIG. 49.

to the lower roll, and guards may be seen along the piece marked *B* in that figure.

Finishing rolls, which do not exert much pressure, and plain rolls for plates and sheets, are made of cast iron with the roll surface chilled to harden it. Blooming and roughing rolls are made of cast steel to withstand the enormous shocks of heavy work. Structural rolls are made of cast steel.

Roll surfaces are first turned to shape in large lathes and are then ground by special appliances to a true surface.

157. Reheating of Blooms, Slabs and Billets.—Reheating furnaces are of many forms according to the fuel used, the size and shape of the material to be reheated, and the rapidity demanded in handling the heated material. The largest types of reheating furnaces are those used for heating armor and other large ingots

to be shaped under the hydraulic forging press. These furnaces are heated usually by the regenerative system. The smallest types are possibly the small portable oil-burning furnaces for heating rivets, and used also for heating small material to be forged. The fuels used are long-flame coal, crude oil, or gas, and usually a smoke stack is necessary to take away the products of combustion, but

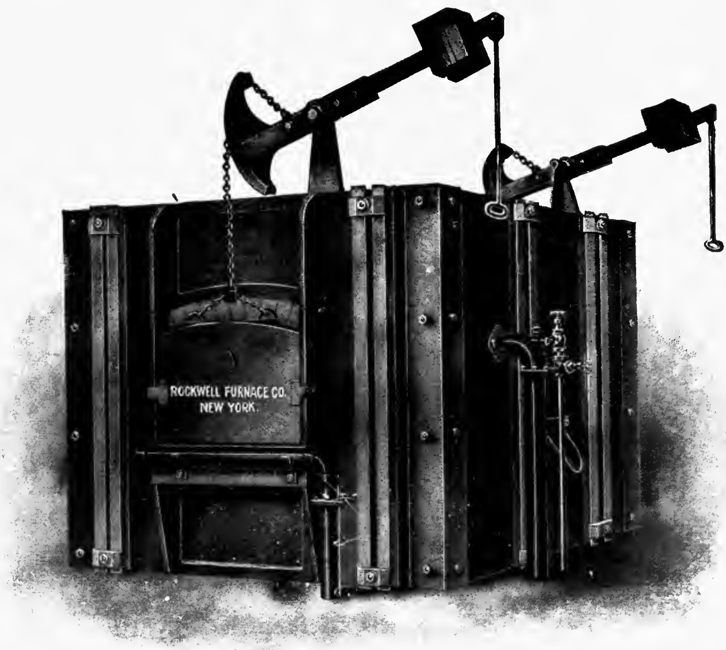


FIG. 50.—Furnace for Reheating Billets.

many oil and gas furnaces have no smoke stacks. The reverberatory type of furnace, with end or side door in the fuel space, and end or side doors in the heating space, according to the convenience of each specific case, is much used for reheating.

Fig. 50 shows a small furnace for reheating billets. This is equipped for burning oil and has a door at each end. The flame from the oil burner (at the side) is directed into the heating space through a hole in the furnace wall.

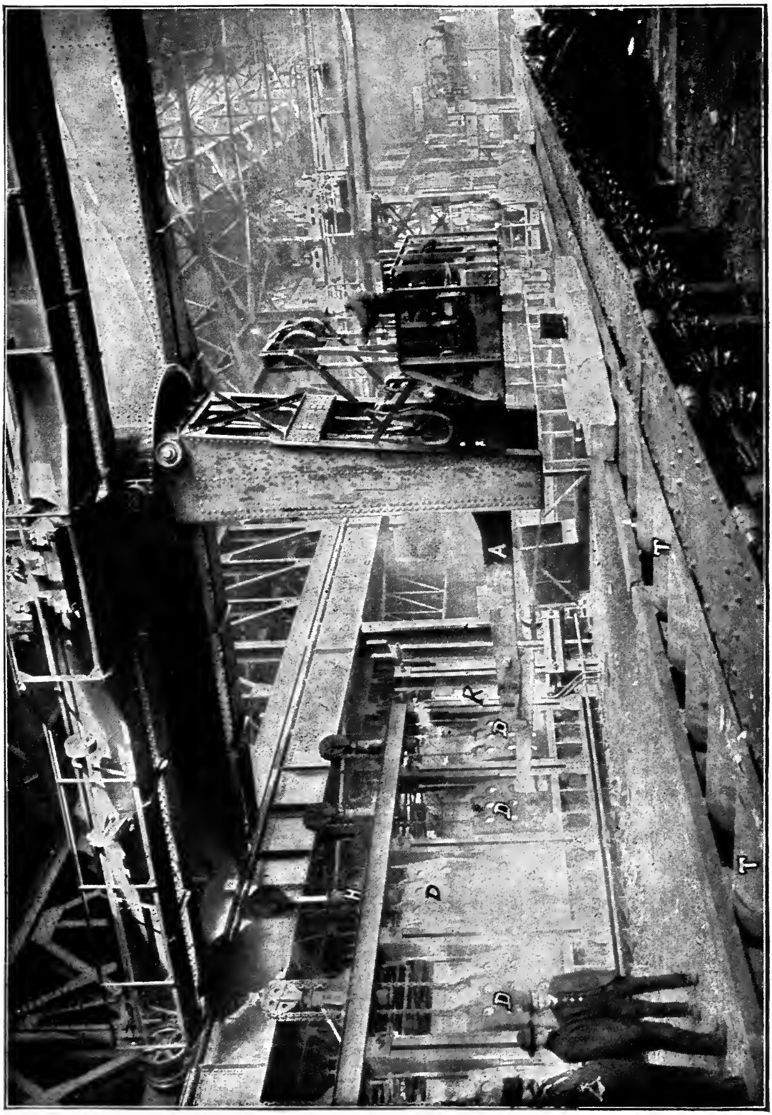


FIG. 51.—Regenerative Reheating Furnace and Charging Crane.

A reheating-furnace bottom is usually a flat magnesite bottom, sloping slightly to one side. The soaking-pit is a reheating furnace, but it is adapted only to ingots, which can stand on end.

The continuous furnace is a type much used. This is equipped with a gravity slide or suitable mechanism for moving a continuous line of material through the furnace in a given time, and the heating is accomplished while the material is passing through.

158. Reheating Furnace for Large Blooms.—Fig. 51 shows the front of a regenerative heating furnace for blooms and other large material, with the charging crane used to handle heavy material. This furnace is modeled like the open-hearth steel furnace. The whole of one side is enclosed by doors *D*, which open into one common heating space. Connection with the regenerative heating system at one end of the furnace is shown at *R*.

The crane has an arm *A*, with electrically controlled tongs or fingers at the end, which now holds a bloom ready to be conveyed through the open door into the furnace. This arm may be swung in a horizontal plane, with slight vertical movement for lifting or lowering blooms. The roller table *T* may be used to convey cold blooms within reach of the crane, and to convey hot blooms to the hydraulic shears in the background of the view.

159. Precautions in Reheating High-Grade Steel.—To avoid the formation of scale in reheating metals, *i. e.*, the waste of the surface by oxidation, the furnace flame should be a reducing and not an oxidizing flame. No risks of oxidation can be taken with high-carbon and alloy steels (usually crucible steels) as any change in the carbon or alloying metal would reduce the quality of the steel. To avoid oxidation, each billet is coated with fire clay, sand and borax, or other harmless, refractory mixture, and placed in the furnace. After removing from the furnace, this mixture is broken off before the billet goes to the rolls or the hammer.

160. Points for the Inspection of Rolled Material.—Steel may be good or bad in quality due to the substances it contains, and steel which is good when tapped from the furnace may be made bad by subsequent casting, reheating and mechanical treatment. Rolling improves the strength of a metal and tends to cover up defects.

Specifications for metals, particularly iron and steel, usually require (1) surface inspection, (2) physical testing, which is the actual pulling and bending of specimens of the metal, to determine its strength and ductility, and (3) chemical analysis to determine its chemical constituents. It is intended to mention here only the requirements of surface inspection, as the defects so disclosed are closely associated with casting and subsequent rolling or forging of metals.

Specifications usually provide that the surfaces of metals shall be free from the following-named defects:

(1) Slag.
(2) Foreign substances.
(3) Brittleness.
(4) Laminations.
(5) Hard spots.
(6) Sand or scale marks.
(7) Scabs.
(8) Snakes.
(9) Pits.

These defects are usually caused by:

(1) Slag and oxides which entered the ingot or billet mould from the ladle.

(2) The chilling of ingot corners in cold moulds, and surface laminations and shot caused by pouring metal against the sides of the mould and thus chilling it.

(3) The sudden chilling of the surface of a hot ingot, billet, bloom, or slab when it is taken from the mould or reheating furnace, causing small surface cracks called snakes. These cracks, when not too numerous nor too deep, are chipped from the surface before the material is rolled or forged, as their sides do not weld together when the metal is rolled.

(4) Failure to discard enough of the ends of an ingot or a billet.

(5) Squeezing metal in rolling so that fins press out between the rolls, and subsequently rolling these fins down as laminations or hard streaks.

(6) Not cleaning the mill scale from the upper surface in rolling plates, or other wide shapes, from which scale will not readily fall away due to the movements and jolting of the rolls.

Further than the defects named, rolled products should not be crooked or warped, nor should plates show undue variation of thickness across their width nor along their length.

It is a common practice to keep a record of the identity of every ingot and billet cast, as in this way many defects in finished products may be traced back to their causes.

161. Effect of Mechanical Treatment of Metals.—The pressure of the rolls and the impact of the forging hammer on a piece of metal increase the strength of the metal from 2 to 5 times, according to the composition, the degree to which the metal is heated, and the pressure applied. The composition of a metal determines its ductility and the degree to which its form can be changed by working, while the heat and pressure to which it is subjected determine the depth to which the rolling or hammering is effective. The rolling of a cold metal makes the surface very hard. The strength of a metal is increased by rolling or hammering because (1) blow holes (including microscopic gas cavities throughout the metal) are pressed very small, and because (2) mechanical pressure crowds the metal crystals more closely together, breaking up planes of cleavage along which tearing would naturally take place. The second effect increases strength and hardness, but decreases ductility and the per cent of elongation before breaking. Working a metal very hot does not cause marked changes in its crystalline structure because the crystals are more or less mobile according to the heat, and are helped by the heat to assume their natural positions relative to one another.

Two ingots from the same heat, *i. e.,* produced from the same heat in a converter or furnace, will show different elastic and tensile strengths and different degrees of elongation according to the degree of reduction each undergoes in rolling or hammering.

162. Cold-Rolled Steel.—The colder a metal is when rolled or hammered, the greater the resulting hardness. The depth of the hardness depends upon the depth to which the rolling or hammering pressure penetrates.

There is extensive use for steel rods and bars which have hard, smooth surfaces, both for the hardness and for the smoothness. These resist wear and take an excellent polish. They also show smoothly when nickel-plated. Also, a hot-rolled rod or bar cannot be rolled to exact dimensions, as cooling after rolling decreases its cross-section area an uncertain amount. To produce small steel bars and rods which are hard, smooth, and of exact dimensions in

cross-section, cold rolling is resorted to. The metal is first rolled hot to near the finished size, pickled to remove the oxidized coating and is then passed many times between chilled rolls. Rods up to 5 inches in diameter are rolled in this way, and the resistance to twisting, due to so hard a surface, makes this product useful as shafting for transmitting power in shops.

163. Large Forgings.—Many massive steel products, as armor plate, large gun parts, and large shafting for marine engines or turbines, cannot be rolled because of their shape, or because their size makes rolling far more expensive than forging. These products are shaped from unusually large ingots which are forged either under impact of the steam hammer, or preferably pressed under the hydraulic forging press.

The blow of the steam hammer is delivered quickly, and its force is absorbed at first locally by the metal directly under the impact of the hammer, and as this becomes compacted, the force is transmitted deeper into the metal mass. The hydraulic forging press is preferable to the hammer for large forgings because its pressure makes itself felt entirely through the metal mass.

Some large forgings are made from rolled blooms, but these are commonly made in large manufacturing plants, as shipbuilding plants and locomotive works, by means of steam hammers.

164. The Hydraulic Forging Press.—Fig. 52 shows a press for heavy work. The diagram in Fig. 53 shows the interior features of the press.

This equipment consists of the press, the hydraulic intensifier, and the auxiliary water tank.

A piece of work W is pressed between the dies DD'. Different shapes of dies may be used. The press head H is forced down by hydraulic pressure on the ram P in the cylinder N, and is raised by steam pressure under the two pistons in the cylinders CC. The vertical motion of the press head is guided by the four colums G which conect the anvil with the entablature B and hold the press rigidly against distortion.

Water pressure of about 5500 lbs. per square inch is supplied through the pipe O from the steam intensifier which consists essentially of a steam cylinder J and a much smaller hydraulic cylinder K. Steam admitted under the piston in J communicates the pres-

sure to the water in K through the rod L. Knowing the pressure per square inch of steam in J, the water pressure per square inch in the hydraulic system is found from the relation

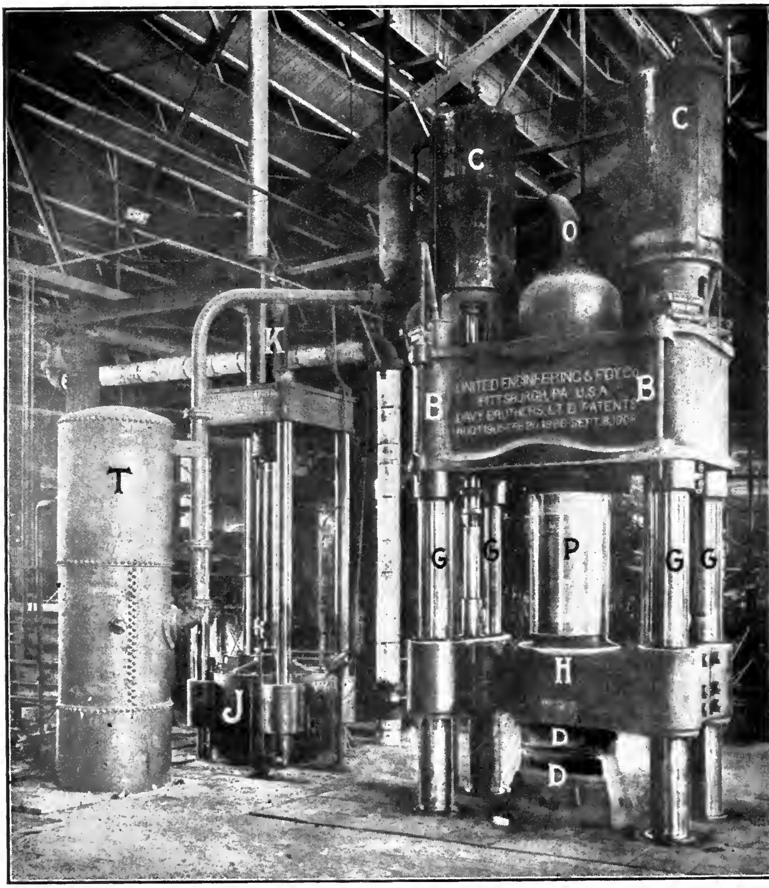


FIG. 52.—Hydraulic Forging Press.

$$\frac{\text{Steam pressure per sq. in. in } J}{\text{Water pressure per sq. in. in } K} = \frac{\text{Area of end of plunger } L}{\text{Area of lower face of piston in } J}$$

A mechanism is fitted to shut off the steam automatically in case the water pressure in K is suddenly lost by any accident.

The entire working of the press is controlled by a single hand-lever ingeniously connected to control the valves numbered 1, 2, 3 and 4.

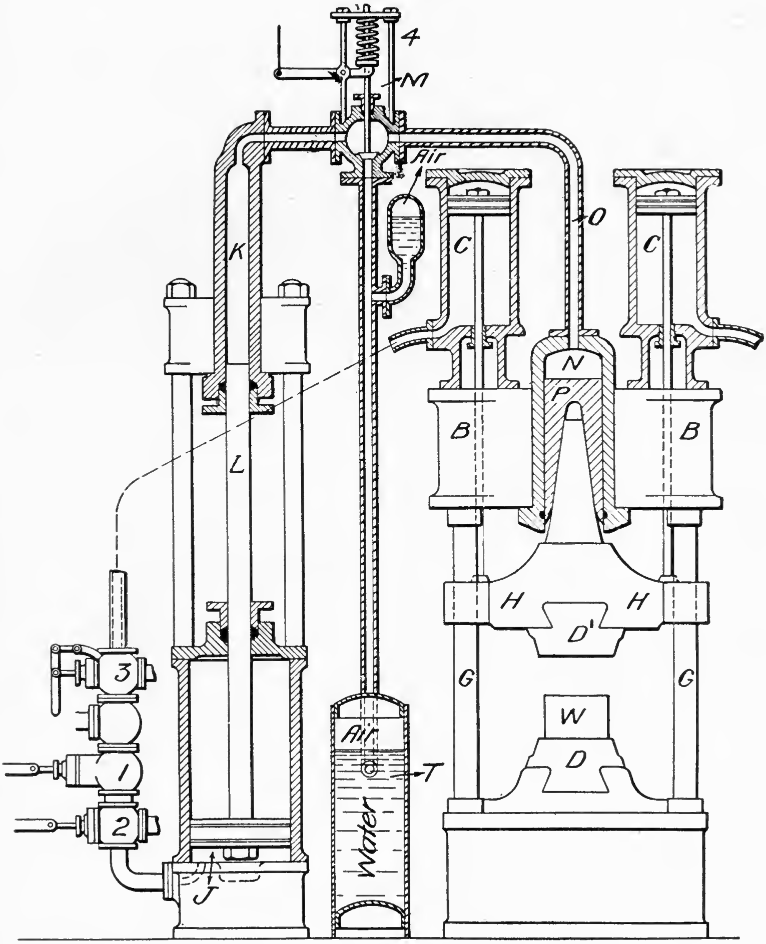


FIG. 53.—Diagram of Hydraulic Forging Press.

Valve No. 1 controls steam to the cylinder J, No. 2 controls exhaust from the cylinder J, No. 3 controls steam and exhaust from the cylinders CC, and No. 4 controls water to and from the tank T through the valve M.

The auxiliary tank T contains air and water under a pressure of 60 lbs. per square inch, and is used as a reservoir for supplying water to or receiving it from the main pipe O. The plunger L may remain quiet and the press head may be lowered by allowing water to flow through the valve M from the pressure tank. Likewise, the press head may be raised by the cylinders CC, with the valve M opened to admit water to the tank against the tank pressure. The system is so arranged that when L moves upward the valve M will close, as great pressure must not be communicated to the tank T.

165. Handling Large Ingots for Forging.—Special equipment must be installed to transport large ingots between the reheating furnace and the forging press and to hold them for the work of forging. The furnace and the press are located conveniently near each other, and a specially built traveling crane is installed for this work.

The upper end of every ingot made for forging is a "crop-end." This end is used to hold the ingot for forging and is cut off when the forging is completed. This end is cast smaller than the body of the ingot and is called the "chuck stub" in the forge shop. Fig. 54 shows the equipment for holding ingots. It consists of a *chuck* B, shown partly in section; a *porter bar* P for balancing and guiding the chuck and ingot; and an endless chain C suspended from a block D. The whole equipment is suspended from and transported by the crane.

The chuck stub is clamped by the set screws in the open end of the chuck. The porter bar is attached to the other end of the chuck. The swivel block D allows the apparatus to be turned readily in a horizontal plane. The heavy spiral spring between the swivel block and the crane hook relieves the crane of any undue shock in forging. It is frequently necessary to hang heavy iron weight to the end of the porter bar to balance ingot, chuck, and bar nicely on the chain. In this way the forge men can easily swing the work by hand pressure on the porter bar. The ingot is turned on its horizontal axes by ratchet attachment geared to the groove G, or it may be turned by an iron bar placed in one of the holes beside the groove.

When the ingot is carried to the furnace for reheating, which may be necessary a number of times in the course of making the forging, the chuck stub sticks out of the furnace door, and the space below the door, when it is closed down on the stub, is stopped temporarily with bricks.

Many different chucks and porter bars are provided in a large forge shop, and some of the porter bars are 60 feet long and nearly

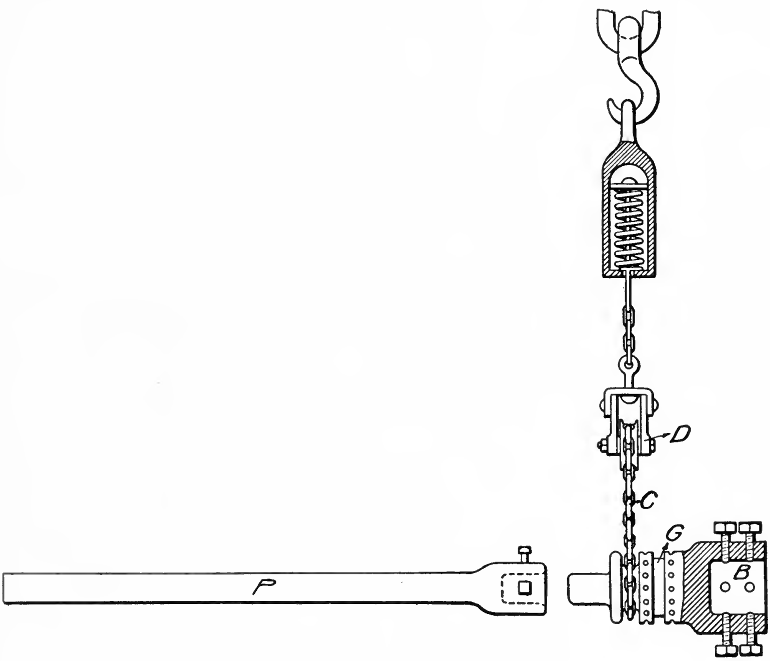


FIG. 54.—Chuck and Porter Bar.

a foot in diameter, which gives an idea of the heavy forgings handled. Gun tubes are forged by the processes just described. Some forging presses, as for forging car wheels, use an intensified pressure of 40,000 lbs. or more per square inch.

166. The Heat Treatment of Metals.—An essential part in the mechanical shaping of a metal is the heating required to make it easily workable without injury to its strength and other properties. Heat treatment includes all heating from the time a metal is cast

into ingots or billets until it goes out in the form of finished products. This is a very extensive subject which is now recognized as highly important by manufacturers of all metal articles, particularly so by manufacturers of articles in steel, because heating not only makes metals plastic, but it changes the crystalline structure of most of them, affecting their strength, ductility and other useful properties.

Carbon and iron are associated in several different relations which are, according to investigators, more or less stable or complicated chemical combinations, all of which may exist in the same mass of steel, and each of which imposes certain properties on the metal and is affected in different ways by heat. This condition makes steel very complex, but a careful study of all these characteristics and of the experimental effects of several kinds of treatment have brought out much useful knowledge on the proper methods of heating steel. Other metals are far less complex, and the changes which come to them in heat treatment are much simpler.

167. Changes in Steel Due to Heating.—It is necessary to heat steel not only to shape it, but to anneal and harden it. That heating for any of these purposes may be properly done, it is necessary to understand certain peculiarities, particularly of high-carbon steels (those containing .2% and over of carbon).

As steel rises in temperature it reaches a point, about 1400° F. (red heat), called the *absorption point*, at which it absorbs a perceptible amount of heat before its temperature again increases. Likewise, having been raised above the *absorption point* and allowed to cool slowly, it reaches a temperature about 50° F. below the absorption point where it seems to give out more heat than is accounted for by loss of temperature. Its glow shows an increase of brightness if observed in a dark room. This is the *recalescence point*. Both of these points are known as *critical points*.

Heating to the absorption point brings the grain of steel to its finest texture. The higher the heating beyond this point and the lower the carbon, the larger the resulting crystals upon cooling. This may be seen, in many cases, by examining fractured specimens

with the unaided eye. This enlargement of crystals reduces strength, hence the size of crystals is a visible sign indicating strength. The smallest crystals may be restored in high-carbon steel by heating it to the absorption point. It may then be cooled slowly or suddenly without change of grain.

Steel need never be heated above its absorption point except to have it amply hot for shaping in a single heat. If high-carbon steel is heated much above the absorption point, its strength is injured, its fracture looks dull, and it is said to be "burned." Such a condition may be impossible to remedy. However, low-carbon steel escapes injury at high heats in most instances, but becomes brittle if heated repeatedly below 1650° F. It is restored to its elasticity if heated above 1650° F.

The crystalline structure of a piece of steel as affected by heat is determined by the five conditions as follows:

(1) Temperature, (2) duration of heating, (3) mass, (4) rapidity of cooling, and (5) whether or not steel cools without being rolled, hammered, or otherwise subjected to pressure or impact.

The presence of nickel, tungsten and other metals used to produce alloy steels have a marked effect upon the critical points of steel. These points are lowered, and the presence of the alloying metals seems to accomplish this by their influence upon the carbon which the steel contains.

168. Annealing of Metals.—When a metal is heated to unequal degrees throughout its mass, or the parts of the mass are cooled at different rates, as is common with large forgings or large castings, or when hammering, rolling, or other work is done on cold metal to change its shape, an arrangement of crystals is forced upon the metal such that some parts of the mass are under stress. For example, a large forging or casting may cool quickly on the surface and, by contracting, pull the hotter parts of the interior into a shape which they would not assume naturally as they cool. Excessive hammering or rolling makes cold metals brittle. In steels, internal stresses and brittleness are most marked when the per cent of carbon is greatest.

Internal stresses, which may be dangerous in many cases, and brittleness in metals worked cold, are relieved by annealing. This consists of heating the mass to a red heat and allowing it to cool very slowly in the case of steel, or plunging into water in the case of copper and some of the copper alloys. Annealing brings metals to their softest and most ductile states.

Steel should be heated to the absorption point for best results and finest grain in annealing, though this is not always done possibly because its importance is not well understood. Steels purposely hardened would lose their hardness if annealed at a high heat, though they may be partially annealed by moderate heating in oil or molten lead, which will relieve the greatest stresses.

Slivers have been known to break and fly with considerable force from extremely hard projectiles while they were awaiting annealing, due to internal stresses.

Annealing is usually done in furnaces not unlike reheating furnaces, though the degree of heat is not so great in annealing as in reheating for working. Coal or wood fires can be better regulated to maintain the low temperatures needed in annealing. To prevent oxidation in annealing, particularly with thin or delicate pieces, the material is placed in a muffle furnace which transmits heat through a brick partition to it, thus preventing contact with the flame, or, better, the pieces are placed in cast-iron boxes, the lids of which are luted with clay, and these boxes with their contents are placed in an ordinary furnace.

Steel forgings and castings demand slow cooling for proper annealing, and it is a common practice to heat them for two or three days in a furnace, then seal up all furnace openings with clay and allow several days for the furnace and contents to cool gradually.

All annealing furnaces must be fitted with pyrometers to gage the degree of heat in obtaining the best results.

169. The Hardening of Steel.—Steels containing above .25% of carbon (approximately) will become hardened if heated to or above the absorption point and suddenly cooled, in water or by other means. The degree of hardness depends upon (1) the amount of combined carbon, (2) the rapidity of cooling, and (3) upon the

range of temperature through which cooling takes place below the absorption point. The rate of cooling of a piece of metal is dependent upon its mass, as well as upon its degree of temperature above that of the cooling medium.

These statements do not apply to steels alloyed with manganese and tungsten. They harden by being heated nearly to melting heat and being cooled fairly rapidly in a blast of air. In this condition they do not lose their hardness when raised to a red heat, and can be used at a red heat for cutting.

170. Oil Tempering of Steel.—Much medium-carbon steel is alloyed with nicked, chromium or vanadium to provide material of superior strength and elasticity for moving parts of marine engines, automobile parts and other fittings where lightness and great strength are desirable in a steel of moderate cost. The strength and reliability of these forgings are increased by a process of heating to a red heat, quenching in oil (a residue of petroleum or a fish oil) and then annealing slightly. The effects of this treatment vary with different percentages of contained carbon and with different quenching temperatures. These have been studied and tabulated at some length by investigators. Gun forgings, and in some processes, armor and projectiles, are oil tempered.

171. Rolling Sheet Copper. The Sheet Mill.—For the manufacture of sheet copper, the metal is cast either direct from the refining furnace, or from remelted pigs, into flat cakes 3 or 4 inches thick. As soon as these cakes have "set" they are dumped into cold water to make them soft for rolling. They must be not less than 99.75% pure for rolling, though all of the impurity allowed must not be wholly arsenic, bismuth or antimony, because the cakes may crack slightly on the surface in rolling.

As soon as the cakes have cooled, their surfaces are examined for spots of cinder, oxide, scale, etc. Large spots are chipped out, or the whole cake may be pickled in dilute sulphuric acid and then scrubbed and rinsed to remove all surface scale. The cakes are taken over to the rolling mill and several are heated at a time to redness in a reheating furnace in order to keep the rolls supplied.

One cake at a time is taken from the furnace and passed repeatedly through rolls such as are shown in Fig. 55. This view shows three 26-inch *pull-over sheet mills.* This type of mill is used for rolling thin sheets of commercial metals, and is called a pull-over mill because a man on the far side of the rolls receives the sheet as it comes through and, by aid of tongs and a guide bar, lifts it so that the man on the front side can pull it over the top roll to pass it again between the rolls.

FIG. 55.—Sheet Mills, Pull-Over Type.

If the sheet is to be finished as soft copper, it is rolled hot down to the thickness required, is then annealed in a furnace to make it of uniform softness throughout, and is pickled to remove roll and furnace scale. The sheet is then straightened by sending it through straightening rolls, or it may be straightened in a stretching machine which grips the ends and pulls the sheet.

If the sheet is to be finished as hard copper, suitable for making pipes, or tanks which must stand pressure, it is rolled hot nearly to the finished thickness, pickled, and then rolled cold in the finishing rolls down to gage. It is then straightened and trimmed to size.

To avoid the formation of furnace scale when heating copper and brass to be rolled, it is a common practice to do the heating and annealing in muffle furnaces.

Cold rolling increases tensile strength, but makes copper and brass more brittle and springy, which is a decrease in ductility.

Sheets of copper, known as planished copper, which are springy and show highly polished surfaces, are cold rolled after having been hot rolled and pickled.

172. Rolling of Sheet Brass.—Brass of the usual compositions is rolled cold into sheets or other forms because the metal will not roll hot. However, if the brass contains less than about 62% of copper it may be rolled hot.

In cold rolling of brass, it takes but a few passes through the rolls to make the metal very brittle. To relieve this brittleness, frequent annealings are necessary. Each annealing must be followed by pickling in weak acid and thorough washing to prepare the sheet for further rolling.

Annealing is done in muffle furnaces at about 700° F., and the metal is cooled by exposure to air, or its cooling may be hastened by sprays of water, if the alloy is such as not to be injured thereby.

In the manufacture of high-grade sheet brass, the plate is subjected to a process called "scalping," after about the second annealing. This process is in lieu of pickling which would otherwise follow this annealing. It consists of placing the sheet on a machine which scrapes the surfaces bright and clean by means of a rapidly oscillating scraper. Successive rollings, annealings and picklings are then given the sheet until it is reduced to the required thickness.

If the sheet is to be finished as soft brass, it must be annealed after the last rolling, and the dull surface due to this annealing is removed by dipping in weak acid, rinsing, and polishing with bran.

Brass may be left with different degrees of hardness and springiness by more or less rolling after the last annealing and not annealing again. New hard brass always has a shiny surface.

173. Extruded Brass.—The process of extrusion produces brass and bronze shapes similar to rolled shapes. Shapes of more complicated cross section can be produced by the extruding process than by rolling. Many brass and bronze compositions will stand cold rolling, but will not stand the extruding process.

Extruding is the process of forcing metal or other substance through a hole in a block of hard metal, usually hard steel. This block of metal is called a die and the hole in it determines the shape of the cross section of the substance forced through it.

Fig. 56 illustrates the principal features of the extruding press as used for brass and bronze. A round billet of brass is cast of such a size as will easily go in the heavy cast-steel cylinder or container *A*. The container may be lifted or revolved so that the billet can be placed readily in the open end at the right. The die *D* having been placed as shown in the view, the red-hot billet is taken from the reheating furnace, is scraped or struck to remove any clinging scale, and is quickly placed in the container which is at once lowered to the position shown. By means of intensified hydraulic pressure

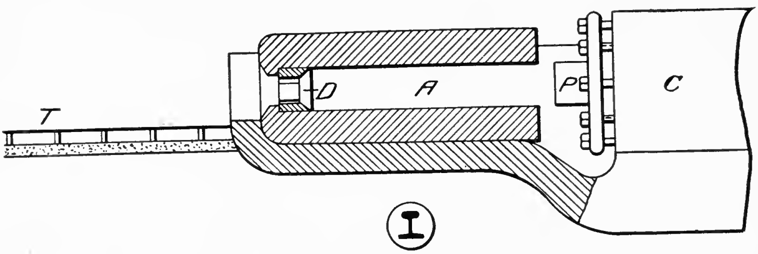


FIG. 56.—Extruding Press.

in the cylinder *C*, the ram *P* is forced against the billet with sufficient pressure to force the metal through the hole in the die. A man stands with tongs ready to grasp the end of the piece as it emerges through the die and conduct it along the metal-covered table *T*, keeping the piece straight so that it may cool straight. The lower sketch shows the front view of a die such as is used for making bronze deck-beams.

A hydraulic pressure, several times intensified, amounting to 60,000 lbs. per square inch is sometimes needed for this work. The weight of billets, limited by the capacity of the container, does not exceed 175 lbs. The quality of the extruded bars is said to be better than that of bars produced by rolling, and certainty the pressure leaves no blow holes and crowds the molecules of the metal closely together. The extruding of metals, hot or cold, is a matter of the power of the extruding press and of the ductility of the metal.

174. Extruded Shapes.—Fig. 57 shows cross sections of some of the shapes produced by this process. Besides the four shapes of bars at the top there are shown a few special shapes as follows:

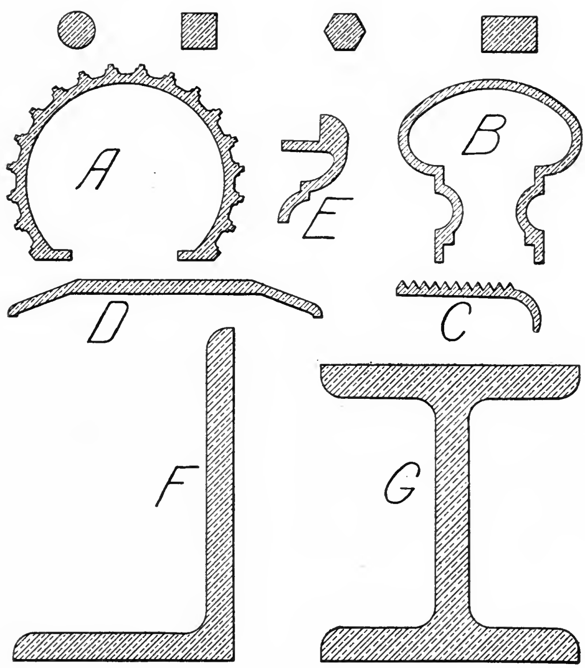


FIG. 57.—Extruded Shapes.

A—Fluted column for interior architectural work.
B—Hand railing for interior architectural work.
C—Stair tread.
D—Door sill.
E—Moulding.
F—Angle bar.
G—I-Beam.

Extruded shapes are extensively used for high-grade interior architectural trimming, as well as for ornamental structural work where strength is a factor. In many cases the bars may be cut in short pieces and thus supply shapes which ordinarily must be produced by casting. The extruded metal needs no further finishing, as it has smooth and even surfaces.

Lead pipe is produced by the extruding process.

CHAPTER VI.

THE RE-MANUFACTURE OF METALS.

175. Scope of Metal Re-Manufacturing.—This branch of metal working includes a great variety of manufacturing industries which shape metals for final uses. In general, the re-manufacture of metals includes all processes which start with rolling-mill products, such as plates, bars, rods, etc., and turn out an endless variety of metal articles which enter into almost every range of service. Possibly the most familiar branch of metal re-manufacturing is that in the shop of the village blacksmith. The blacksmith shapes, by manual labor, many articles from bars, rods and sheets of metal which are supplied by the rolling mill.

By far the greater part of re-manufacturing is carried on in large workshops and factories in which the main part of the work is done by machines operated by persons of more or less skill. A single manufacturing establishment may be employed wholly in making one kind of article, wire for example, or its range may be extended to making articles closely associated, as rivets, bolts and nuts, or automobile forgings.

Only a few of the re-manufacturing industries can be given particular mention here, and those outlined in this chapter are selected either to give information of metal-shaping methods which produce well-known articles, or to show the possibilities of metal working.

A great many metal articles familiarly seen are products of the foundry, where pigs of metal are melted and cast into shape. Foundry products are not usually classed as products of re-manufacture, and will be dealt with later on. They can usually be readily recognized by their more or less irregular form. Superficial inspection will generally show that they are not made from shapes supplied by the rolling mill.

176. Tool Making.—One of the most important branches of re-manufacture is that of tool making. Nearly all tools are made of

steel. Those used for measuring and trying, such as calipers, gages, squares and scales, are sufficiently hard and durable when made of low-carbon steel.

Tools for metal cutting are forged from high-carbon or alloy-crucible steels of the best quality. Carbon steel for tools is commonly known as *machinery steel.*

A lasting keen edge on a cutting tool requires hardness, but hardness and brittleness go together, hence those tools which must stand extreme shocks, battering, twisting, or bending, must sacrifice some of the hardness to tenacity and ductility.

Cutting tools may be forged or cast to approximate shape. The rougher tools may be hardened and then ground to finished shape, but the tools for finer work, as taps and dies, must be machined to shape before they are hardened. The process of hardening may distort a tool slightly, which may ruin it unless it can be brought to its true shape by grinding after hardening.

177. Special Methods of Heating and Hardening Steel Articles.— In the older methods of heating, hardening, tempering and annealing steel, results depend entirely upon the eye and practice of the workman. To insure uniform results, various methods of heating and hardening have been devised which eliminate judgment, and secure automatically the same results in each case.

In manufacturing establishments, tools and small articles to be hardened are usually heated in a bath of red-hot molten lead. Heating may also be done in closed iron tubes or in small muffle furnaces. A pyrometer must be used to regulate the temperature of a heating furnace or a lead bath.

To avoid burning off the sharp points of file teeth and the sharp cutting edges of threading dies, etc., during heating or while transferring these articles from the heating bath to the quenching or hardening bath, the articles are dipped before heating into a thin hot paste of salt, flour and charred leather, or into a hot salt solution. This mixture dries at once and remains on the surface until after the articles are hardened.

For hardening steel, quenching baths of fish oil, petroleum residue, or brine are much used, and are kept at constant and uniform temperature by agitation or by a constant flow from one receptacle to another. These quenching baths are not so sudden

in their cooling effect as is pure water, hence the shock to the metal is less, and the degree of hardness given is sufficient. The consistency and temperature of a quenching bath is determined by experiment to give the degree of hardness required without further process.

178. Sheet Iron.—This product is familiar in many forms. Most of the so-called sheet iron of to-day is sheet steel and not wrought iron as it was before the days of mild steel. This sheet steel for common uses is a very soft grade of mild steel, very pliable and easily worked. It is much used by the tinsmith and is the stock material for the sheet-metal-shaping trades and manufacturers. It is familiarly seen made up as stove pipes, steam-pipe lagging protectors, oil guards, etc., and is either of dull surface presenting faint waves of color due to annealing, or is shiny black.

The dull black sheets may be marketed either as such or in the following forms: (1) Crimped into *corrugated iron,* much used for covering warehouses or other buildings; (2) coated with zinc and known as *galvanized iron;* (3) coated with tin and known as *tin;* and (4) planished with carbon and called *planished* or *Russia iron.*

179. The Manufacture of Sheet Iron.—Sheet iron (as it is commonly known) is made by rolling sheet-bar into thin sheets, as was stated in Par. 154.

At the sheet mill, the operation of rolling sheets is as follows: The 30-foot sheet-bars are cut into short lengths, heated in a reheating furnace, and run through the rolls sidewise, as the width of the bar is stretched out to form the length of the sheet. Rolling stretches metal in the direction of its travel through the rolls and very little if at all in the direction of the axes of the rolls, hence bars are cut into lengths but slightly longer than the width of the sheets to be rolled from them. A mill similar to that for rolling sheet brass and sheet copper is used for this work.

After about the first five passes through the roughing rolls the bar has stretched out greatly, is very thin, and wobbly while hot, hence, for easy handling it is folded double, and two thicknesses of metal pass through the rolls at once. The sheets are not hot enough to weld, and their scale keeps them from sticking together. This doubling is called "matching." This doubled sheet

is then reheated with three other matches, and all are given one pass through the smoothing rolls together, thus making six thicknesses of metal in one pass. These six sheets are allowed to cool and are then sheared along the ends and the edges, after which they are "opened" or taken apart.

The sheets then go to the cold rolls through which they are passed singly one or more times to give density and smoothness, after which they are piled about one hundred in a pile for annealing. Fig. 58 shows a heavy tray *C* on which sheets are piled for annealing. The cover *T* is placed over the pile and sand is placed all around the lower edge of the cover to exclude air. The cover and tray are lined with fire bricks and suitable lugs are fitted for handling by the crane.

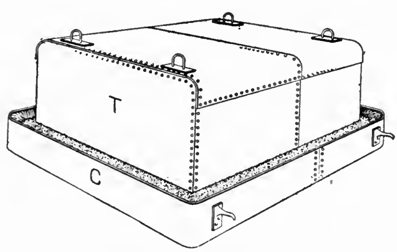


FIG. 58.—Annealing Tray for Sheet Iron.

Annealing requires about 12 hours. When cold, the cover is lifted and the sheets are stripped apart by hand. After inspection, they may be bundled for market as "dead soft" sheets, or may be sent to other departments to be corrugated, tinned, galvanized or planished.

If hard sheets are required they are selected from the cold-rolled stock before annealing.

180. Galvanizing.—This consists of covering articles of iron or steel with a coating of zinc for the purpose of resisting corrosion.

Articles to be galvanized must first be pickled in a dilute acid to remove or loosen all surface dirt and scale. Upon lifting from this bath, the articles are well brushed with brooms or steel brushes and are washed with fresh water from a hose. They are then placed in a second bath of weak acid (usually HCl) to insure a clean metallic surface and must be taken directly from this bath

to a "flux tank" to avoid rusting, which would occur if exposed unduly to the air. The fluxing mixture consists of a solution of sal ammoniac kept hot by steam pipes and covered with beef tallow, and is used to neutralize the acid of the two preceding baths. From the fluxing bath articles are lifted dripping, and immediately lowered into the galvanizing bath, known as the "zinc pot." This bath consists of molten zinc, which soon becomes covered with flux and dross, and is protected by these from the oxidizing action of the air. The zinc pot is an iron tank which is surrounded by brick walls with space enough between the walls and the tank to maintain a coke fire for keeping the zinc melted.

Small articles are lowered for a moment into the zinc bath in wire baskets. They are lifted out and allowed to cool.

The best grade of galvanized sheets is produced by feeding the sheets taken directly from the fluxing bath into a machine which is submerged in the zinc pot. This machine is merely a series of rolls which draw the sheet into the bath, carry it down near the bottom, and finally send it out over the further edge of the pot. These rolls insure an even coating of zinc over the surface of the sheet and roll down all lumps and uneven places. Sheets from the zinc pot are placed on edge in racks to cool, and are then run through straightening rolls and sorted to pick out sheets which are imperfectly galvanized. The imperfect sheets are returned to the second acid bath if very imperfect, or are bundled and sold as "seconds" if only slightly imperfect. All sheets are branded before bundling for market.

181. Tinning.—Tinning, like galvanizing, is a practical method of coating iron and steel to render it non-corrodable. Tinning gives a smoother, brighter and better-looking surface, and it forms a more durable coating, than does galvanizing. Very common among tinned products are tinned wire, roofing tin, tin-lined cooking vessels, and cans in which preserved fruits and vegetables are held.

182. The Manufacture of Tin Plate.—This process is very similar to the process of galvanizing, but is more elaborate, and requires more care, as the product is used where resistance to corrosion is more essential.

Sheets to be tinned are rolled from sheet-bars and are then trimmed to measure 14 x 20 inches, the standard size for tin plate.

After rolling and trimming, the sheets are selected with more care than for galvanizing. They are then pickled and rinsed to expose smooth, clean surfaces, and are annealed on a covered tray. Annealing makes them too pliable for use, hence each sheet is given two passes through finishing rolls to make the surfaces smooth and to make the sheet springy or elastic. This annealing and rolling makes another pickling necessary, after which they are kept under water to avoid oxidation while waiting to go into the tinning pot.

The coat of tin is applied by immersing one sheet at a time in an iron pot containing molten tin. The sheet enters the tin through

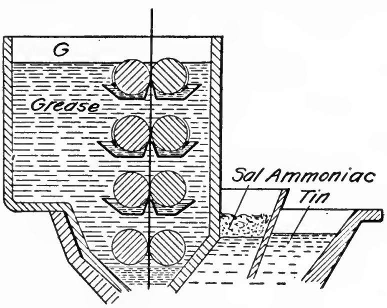


FIG. 59.—Tinning Pot.

a flux of ammonium chloride (sal ammoniac) which floats on the surface of the molten metal and prevents the formation of dross, which would cling to the surface of the sheet. Fig. 59 shows a diagram of the upper part of the tinning pot, on the back edge of which is mounted a grease pot *G* filled with molten palm oil, in which revolve several pairs of rollers as shown. The sheet is lifted from the pot until gripped by the lowest pair of rolls, and it is carried upward by these and the other rolls which deliver it to a table above the grease pot. The palm oil serves to keep the plate hot and to prevent oxidation while the rolls are pressing off superfluous tin and smoothing that retained on the sheet. The slower running of the rolls allows a heavier coating of tin to stick to the sheet. The tin in the pot is kept molten by gas burners not shown.

After emerging from the grease pot, each sheet is forced up,

edge on, through a bin of sawdust and lime to clean it, and is then passed through buffing and dusting rolls, after which it is carried to the sorting tables. The work of sorting is usually done by girls, who grade all sheets as "primes" (1st grade) or "wasters" (2d grade). Some "wasters" having no defects except a few poorly tinned spots may be "mended" by cleaning and retinning, thus making "primes," but "wasters" with bad defects must either be sold as seconds or thrown out entirely for remelting and recovering the tin.

Tin plates are usually packed 112 sheets to the box.

183. Terne Plates.—This is a grade of tin plate used for roofing. Terne plates are slightly heavier than tin plates and are much cheaper, as they are covered with a mixture of about 25% tin and 75% cent lead. Many tin vessels, not intended for food receptacles, are made of terne plates.

184. Russia Iron.—This name is applied to sheet iron of very highly polished or glazed surface also known as *planished* iron. It is used for protecting the lagging of engines and boilers and for other uses where a non-corroding black iron of finished surface is desired.

These sheets are made by piling together about fifty pickled sheets of soft steel with powdered charcoal sprinkled between adjacent sheets. The pile is wrapped in old sheets, wired and heated in a furnace to a cherry-red heat for about 6 hours. Upon cooling, each sheet is swept free of loose charcoal and is then sprayed with steam to form a thin oxide. Again the sheets are piled together, heated and then placed on the hammer table, several in a bundle, and pounded with a steam hammer. This brings about a grinding action which grinds the carbon and oxide on the surface down to a highly polished coating.

185. Wire Drawing.—Metals to be made into wire are first cast (or rolled in the case of wrought iron) into long square billets. A billet intended for wire is about 4 x 4 x 56 inches. Brass and copper billets are also called "wire bar," when cast for making wire.

The first operation is to break down these billets in billet and rod mills. A billet is run hot through a continuous mill of about eight sets of rolls, which break it down to about 1⅛-inch square

cross section. It then goes at once through the looping rod-mill which delivers it as coiled rod varying from 3/16 to 3/8 inches diameter, and a hundred or more feet in length.

These coils are sent to the wire mills and the remainder of the process of reducing them to the diameter of wire required is accomplished by drawing them cold through dies.

At the wire mill, coils must first be pickled to remove all scale. After this they are dipped in lime water and dried in a steam-drying room where they remain until removed to be drawn.

Fig. 60 shows in cross section a steel die for wire drawing. The work of drawing is done on the draw bench, as shown in Fig. 61,

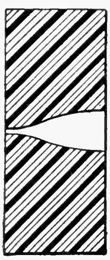


FIG. 60. Wire Drawing Die.

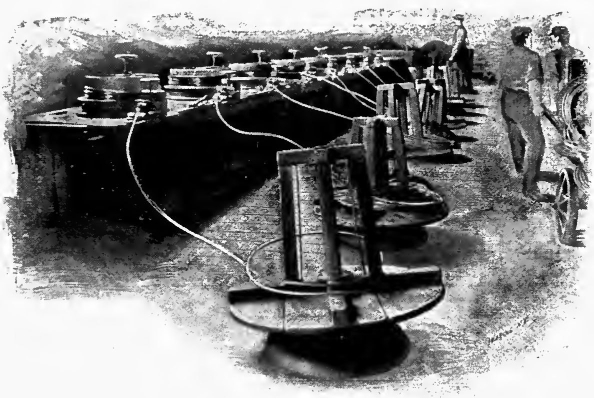


FIG. 61.—Wire-Drawing Bench.

which is a long bench against the shop wall. Along this bench are mounted, on vertical spindles, a row of short cylindrical drums about 22 inches in diameter. These drums, known as "drawing blocks," are made to revolve by being geared to a long shaft under the bench. A drum resembles somewhat a car wheel, with the flange at its lower edge, and each drum may be stopped at will while the remainder on the bench continue in motion. Near each drum, at the edge of the bench, is a small vise, or "frame," which holds the die.

A coil of rod from the drying room is placed on a reel fastened to the floor near each frame on the draw bench, and a rod end is filed

or hammered so that it will pass through the die. An appliance on the bench pulls about 6 feet of this end through the die. A workman fastens this end to the drawing block and starts the block in motion. The revolutions of the block draw the rod through the die and the wire is wound on the block, which continues in motion until the entire rod is drawn through.

The percentage of reduction in diameter accomplished by the die depends upon the softness of the rod. Drawing must necessarily pull a metal beyond its elastic limit, else the metal would not remain in the shape drawn, but the metal cannot be pulled too near its tensile strength, else it would break.

After one or more drawings, the coil must be taken from the block and annealed to soften it and relieve it of brittleness. To prevent scale forming on the wire in annealing, several coils are placed in an annealing pot which is sealed and heated in the annealing furnace. Successive drawings and annealings are continued until the wire is reduced to the diameter required.

Manufacturers lubricate wire dies with oil, solid grease or a ferment of bran and yeast in water. Common wire is made usually of acid Bessemer steel. Sounding wire, piano wire and other high-grade wires are made of crucible steel or of open-hearth steel refined in the electric furnace.

186. Gaging the Sizes of Wire.—For designating the diameters of wire, thicknesses of sheet metals, and thicknesses of the walls of tubes, various arbitrarily chosen scales of sizes are used in America and in Europe. These sizes are designated as wire-gage units. For example, a wire may be designated as No. 5, B. & S. (Brown & Sharpe) or No. 5, B. W. G. (Birmingham Wire Gage).

The several systems use numbers to designate sizes ranging from 0000000 (usually expressed as 7/0) to 50, although the sizes are of different dimensions in the different systems.*

In America the B. & S. gage (prepared by Messrs. Brown & Sharpe Mfg. Co., Providence, R. I.) is standard among manufacturers for designating wire sizes and metal thicknesses, although the U. S. Navy Department has adopted the B. W. G. (Birmingham

* A table in the Appendix gives a comparison of the different wire-gage systems.

Wire Gage) for designating thickness of *walls of pipes* and *tubes,* and the U. S. standard gage for designating *steel* and *iron*-plate thicknesses.

The finest wire drawn is a copper wire of about .001-inch diameter.

187. Coating Wire for Protection from Corrosion.—Most of the iron wire of to-day is made of low-carbon steel, which corrodes very quickly. The cheapest protection is galvanizing, though tinned or coppered wires are more effectively protected.

Galvanizing and tinning are done by passing wire from one reel to another first through a bath of weak hydrochloric acid to clean it, then through a wiper of waste. It is then pulled under suitable guides through a bath of molten zinc or tin, according to whether the process is galvanizing or tinning, and from this bath it passes through a wiper of asbestos fiber to remove lumps of the coating material before it cools and is wound into a coil.

Pickled wire coils dipped into copper-sulphate solution take a coating of copper, and when drawn the wire has a bright copper surface.

188. Hard Wire. Spring Material.—Drawing hardens wire and the hardness differs in degree according to the composition of the wire and the amount of reduction without annealing. Wire which is not annealed after drawing is called "bench-hardened" wire. Steel wire containing as high as 1.20% per cent of carbon is drawn cold, and this may, if desired, be made harder just as steel tools are hardened. High-carbon steel wire is generally marketed in straight lengths of a few feet, annealed, and it is hardened as may be desired by the user.

Flat wire or ribbon wire, containing about .9% of carbon, such as is used for clock and watch springs, is drawn the same as round wire, though the large sizes for coiled springs must be rolled. This material is hardened and tempered while winding it from one reel to another. It passes through an oil flame to heat it to redness, then through cold fish oil to harden it, and last through molten lead, kept at a fixed temperature by oil burners, to anneal it. The hardness cannot be such that the material will snap if rolled into coils.

Wire is very soft and pliable if thoroughly annealed after drawing.

189. Pipes and Tubes.—These two words are much confused in their applications. Commercially, there are many kinds of pipes and tubes of many sizes and materials.

The pipe and tube-making processes described in the following paragraphs embody the essential principles of making pipes and tubes of all kinds in which ductile metals are used.

Cast-iron pipes are much used for large water, oil and gas mains. These are products of the foundry and will not be described here.

All pipes and tubes made of wrought iron or mild steel are manufactured by one of two general processes; either by shaping metal strips called "skelp" into cylindrical form and welding the edges together; or by drawing the tubes from solid billets or flat plates. The products of these two processes are classed respectively as *welded* or *seamless*.

190. The Manufacture of Welded Pipe.—Most of the welded pipe is now made of a low-carbon acid Bessemer steel. This steel will weld readily, and it has nearly displaced wrought iron for this use.

Billets are rolled into skelp (which is similar to sheet-bar) of the width and thickness required for the pipe. Each strip of rolled skelp is cut into lengths of about 20 feet, and each length is made into a pipe.

Welded pipe is made either by lap or butt welding of skelp strips. Pipes of 1¼ inches diameter and under are butt welded, as shown in Fig. 62 and those over 1¼ inches diameter are lap welded as shown in Fig. 63.

The methods of welding are as follows, viz.:

For Butt Welds.—In a long flat-bottomed heating furnace with a door at one end for receiving strips and a door at the other end for removing them, a number of strips are kept side by side at various degrees of heat up to welding heat. When a strip has reached welding heat, a man reaches in at the removing door with a long pair of tongs and curls over the edges for a few inches along the end of the strip. Working quickly, he pulls the end from the furnace,

points it through a tapered ring known as a bell (*B*, Fig. 64) and grips this end with the nippers *R*. Just the instant the nippers grip the strip, the hook *H* is caught by a moving endless chain under the bench and the strip is pulled through the bell. The bell is so shaped that it rolls the strip into cylindrical form and forces

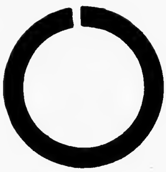


FIG. 62. **FIG. 63.**

Butt and Lap-Welded Pipe Joints.

the edges together firmly enough to make the weld. The bell rests against a shoulder *S* on the bench while the strip is passing through, but when through, the bell falls into a basin of cooling water and another bell is held in place by tongs ready for another strip to start through.

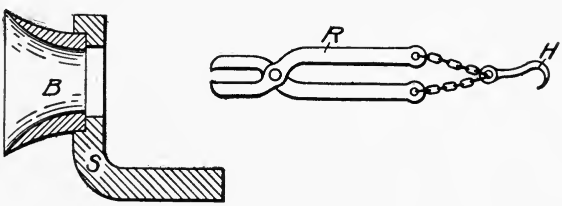


FIG. 64.—Equipment for Making Butt-Welded Pipe.

For Lap Welds.—The shaping and the welding are accomplished in two heatings. The first heating is merely a red heat for shaping the strip into cylindrical form, a process similar to that for butt welding. The second heating is for welding the pipe.

It is apparent that the bell of Fig. 64 will not bring the lap firmly together for a lap weld, hence after the pipe has been given a cylindrical shape, it is reheated to welding heat in another fur-

nace and run through the welding rolls *RR,* Fig. 65. A view of the actual machine is shown in Fig. 66. The rolls are two grooved

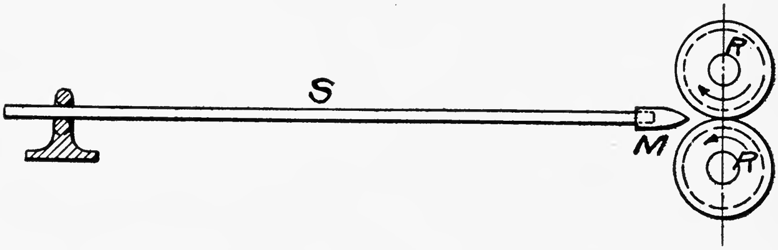


FIG. 65.—Rolls and Mandrel for Making Lap-Welded Pipe.

wheels which press the lapped edges together against a mandrel *M* placed in the end of the pipe as it enters the rolls. The mandrel is held *directly between* the two rolls by the long rod *S*. The pres-

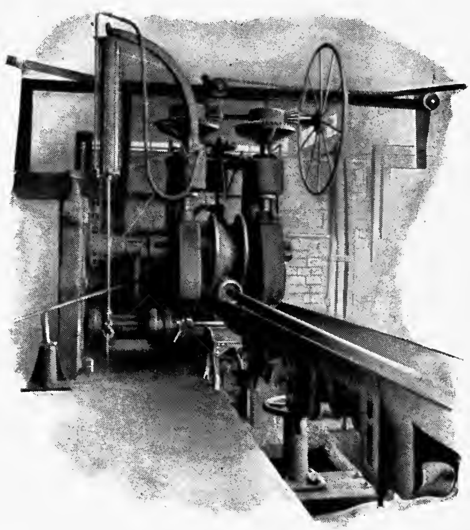


FIG. 66.—Machine for Lap-Welding Pipe.

sure of the rolls forces the pipe against this mandrel and makes the weld.

After welding, both butt and lap-welded pipes are run cold through sizing rolls, which gives them correct outside diameter, and through

cross rolls, which straighten them and give the surface a clean finish. The pipes then go to the inspection table, ends are sawed off, and the short pieces are crushed cold to show the effectiveness of the weld. The pipe is carefully inspected outside, is tested by hydraulic pressure of at least 600 lbs. per square inch, and, if passed, it is annealed to reduce the size of the crystals and increase the elasticity.

Pipes are threaded on the ends after annealing and are then ready to be made up in bundles for shipping. Each length of pipe is shipped with a short threaded sleeve called a coupling screwed on one end of the pipe. This is used in joining lengths of pipe together. Some grades of boiler tubes are produced by the lap-welding process.

191. Defects in Welded Pipe.—Besides defective welds, the following named defects in welded pipes, with their causes, may be mentioned:

(1) *Cracks or Seams.*—These originate in the ingot as blow holes, shrinkage, cracks or other defects. An ingot defect lengthens out when the material is rolled into skelp.

(2) *Blisters.*—These are caused by piping in the ingot. Heat swells them above the surface of the skelp.

(3) *Scale Pits and Sand Marks.*—These are small indentations caused by rolling scale or sand into the surfaces of the skelp.

192. Iron Pipe.—Welded pipe is commonly seen and much used as steam, gas and water pipe, and is commercially known as *iron pipe.* It is made in standard sizes designated in inches as follows, viz.: $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, $4\frac{1}{2}$, and in sizes of even inches from 5 to 12, both inclusive. These sizes refer to the inside diameters of the pipe, but, as a matter of fact they are only nominal, as the actual diameters differ more or less from the designated diameters. While iron pipe is referred to by its nominal *inside* diameter, it is standardized in size in *outside* diameters.*

Iron pipe is marketed either galvanized or plain, and some makers coat pipe with asphalt or tar.

For very heavy pressures, or for driving oil or artesian wells, two special thicknesses of iron pipe are made, known commercially as

* Paragraph 437 of the Appendix gives a table of sizes and dimensions of standard iron pipe.

extra strong and *double extra strong.* These have the same external diameters as the standard piping. Also, iron pipe is made much larger than 12 inches in diameter for many uses.

Iron pipe is much used as underground conduits for electric wires.

193. Seamless Tubes.—It is not commercially practicable to produce a welded tube which shall uniformly have the same strength at the weld as in other parts of the metal. The temperature to which it is necessary to heat the metal for welding is such that the material may be burned to a greater or less extent, a condition which it is not always possible to detect.

For these reasons, boiler tubes and other tubes or pipes which must stand high pressures and which are subjected to great variations of temperature, are preferably made without welds or seams.

There are several methods for producing seamless tubes which are applied to various materials, including steels of practically all compositions, brass, copper, etc. The method of making seamless tubes in general use consists in piercing a hole axially through a billet of circular cross section, reducing the wall thickness of the tube so produced by rolling, and finishing, when the conditions require, by further reducing the wall thickness by cold drawing. Some compositions of brass will not stand piercing, hence tube billets of these compositions are cast hollow and reduced in size by drawing.

194. Piercing Billets for Seamless Tubes.—This first operation in making seamless steel tubes begins with small ingots supplied by the rolling mill, free from surface flaws. These ingots are heated and rolled into cylindrical form, and are sawed hot into lengths required. Each of these lengths, called a *blank,* may range in weight from 40 to 1000 lbs., according to the size of tube to be made.

When cold, a hole about $5/8$-inch diameter and $3/4$-inch deep is drilled in the center of one end of each blank, and the blanks are then reheated to about 2200° F. for piercing.

The reheating furnace may be any of the various types used for heating billets. The bed of the furnace is usually inclined so that blanks may gradually roll in a continuous line one against another through the furnace.

From the furnace, each hot blank is taken directly to the piercing mill, the principle of which is shown in Fig. 67. This is the Stiefel mill, and is used more than other mills in this work. The principle of operation is the same in all piercing mills, and they vary only in their mechanism.

The discs *A* and *B*, beveled alike on the faces, revolve in the same direction, and their axes *X* and *Y* are parallel. The blank *K* is supported in a trough so placed that its axis, *DD*, makes equal angles with the face *C* and with the bevel *F* of the two discs; also the axis *DD* is in the same plane which contains the axes *X* and *Y* of the discs.

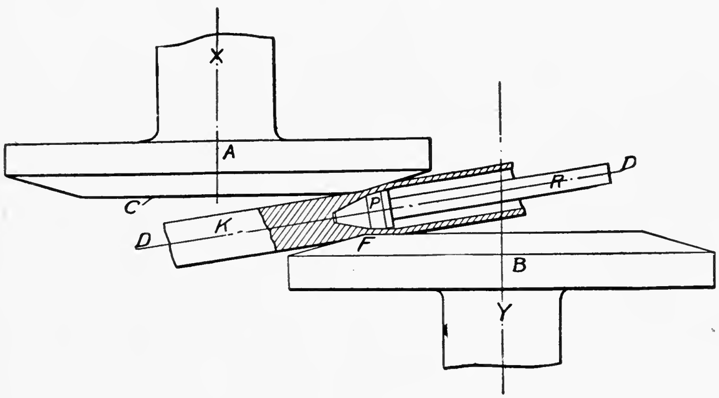


FIG. 67.—Making Seamless Tubes. Piercing Rolls.

The blank is pushed by a bar in the hands of workmen until gripped by the discs, which take hold of it, giving it a rotary motion and forcing it against the piercing mandrel *P*, a conical piece of cast steel held in place by the piercing bar *R*. The piercing mandrel is made to start centrally by the small hole drilled in one end of the blank, and the piercing bar is held to its place by a thrust bearing which allows it to revolve freely. The motion of the discs gives the blank a motion of translation in the direction of its axis, besides the rotary motion. This forces the blank entirely over the piercing mandrel in a few seconds, and the operation of piercing lengthens the blank into a tube from two to four times the length of the blank.

This tube is in a rough state after piercing, not uniform in diameter and with a surface somewhat wavy. The original process of piercing tubes, invented by the Messrs. Mannesmann gave the pierced blank a spiral twist. This was found to be a disadvantage, giving an unnecessary strain to the metal of the tube walls, and the Steifel process is among those devised to reduce this fault.

To smooth the tube up and give it uniform diameter, it is subjected to five finishing operations, with or without reheating, according to the size of the tube. These operations are:

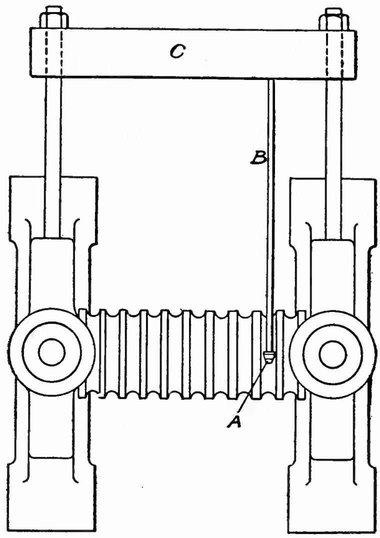


FIG. 68.—Making Seamless Tubes. Tube Rolls.

(1) Rolling the pierced blank to give uniform diameters and thickness of wall.

(2) Cross rolling, to remove scratches and smooth the tube surface.

(3) Sizing, to reduce the tube to a specified diameter.

(4) Straightening.

(5) Cutting to length.

195. Rolling Pierced Blanks.—This operation is done by two grooved rolls. Fig. 68 shows a plan view of this machine with the upper roll removed.

These rolls force the tube over a fixed mandrel *A* supported between the rolls by a bar *B*. The bar is supported by a yoke *C*. Several passes through the rolls over the mandrel *A* reduce the tube wall to the thickness desired, and give uniform diameters. The size of the mandrel and of the roll passes determine the thickness and diameters of the tube. This operation leaves scratches inside the tube which are removed in the next operation.

196. Cross Rolling.—This work is done in a *reeling machine*, the principle of which is shown in Fig. 69.

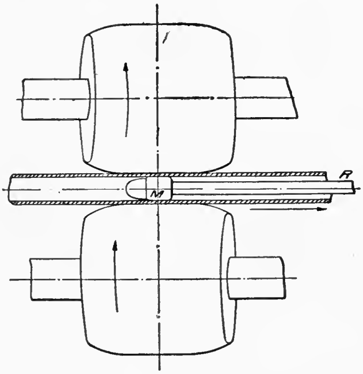


FIG. 69.—Making Seamless Tubes. Tube Reeling Machine.

Supposing the axis of the tube to lie in the plane of the page, the axis of the upper roll is inclined downward toward the right, and that of the lower roll is inclined downward toward the left. The revolutions of the rolls inclined in this way not only revolve the tube, but push it forward over the mandrel *M*. The mandrel is supported by its bar *R*, and is free to revolve with the tube. This operation may change the tube diameter somewhat.

197. Sizing.—This is done by a small two-high rolling mill the rolls of which have circular passes of two sizes. The first pass reduces the tube to within 1/32 of an inch of the finished diameter and the second pass reduces it to finished diameter plus a small amount which the diameter will contract in cooling, as the tube is now at a dull red heat.

198. Straightening and Cutting to Length.—After sizing, the tube is transferred to a machine which consists essentially of a pair of cross rolls as shown in Fig. 70. The axes of these rolls, BC and DG, are inclined at equal angles on each side of the tube axis KL. The tube is pushed through in the direction of its length between the two rolls, which revolve in the same direction.

The arrangement of these rolls is identical with that in the reeling machine. They are much longer than the reeling rolls. Their surfaces are hyperboloids of revolution and each face is generated by a straight line $K'L'$ revolving about an axis $B'C'$ at a fixed distance OS from it. The two rolls are so inclined that the

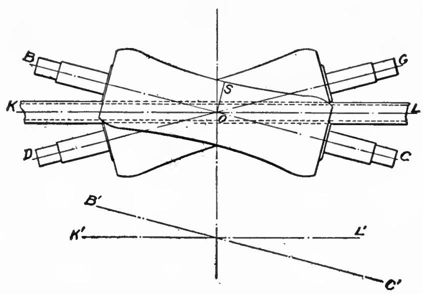


FIG. 70.—Rolls for Straightening Tubes.

contact of the tube with the rolls approximates a generating element as near as possible.

Suitable guides prevent the tube from taking any lateral movement.

From the straightening rolls, the tube is sent to the cooling table, down which it rolls gradually, against other tubes, to keep it straight as it cools.

The hot work on the tube is now complete, and without further operation than cutting to length and testing, these tubes are suitable for use as boiler tubes or for many mechanical and structural purposes.

After cutting to length in a simple cutting machine, each tube is tested to an internal hydrostatic pressure of 1000 lbs. per square inch, is carefully inspected and marked.

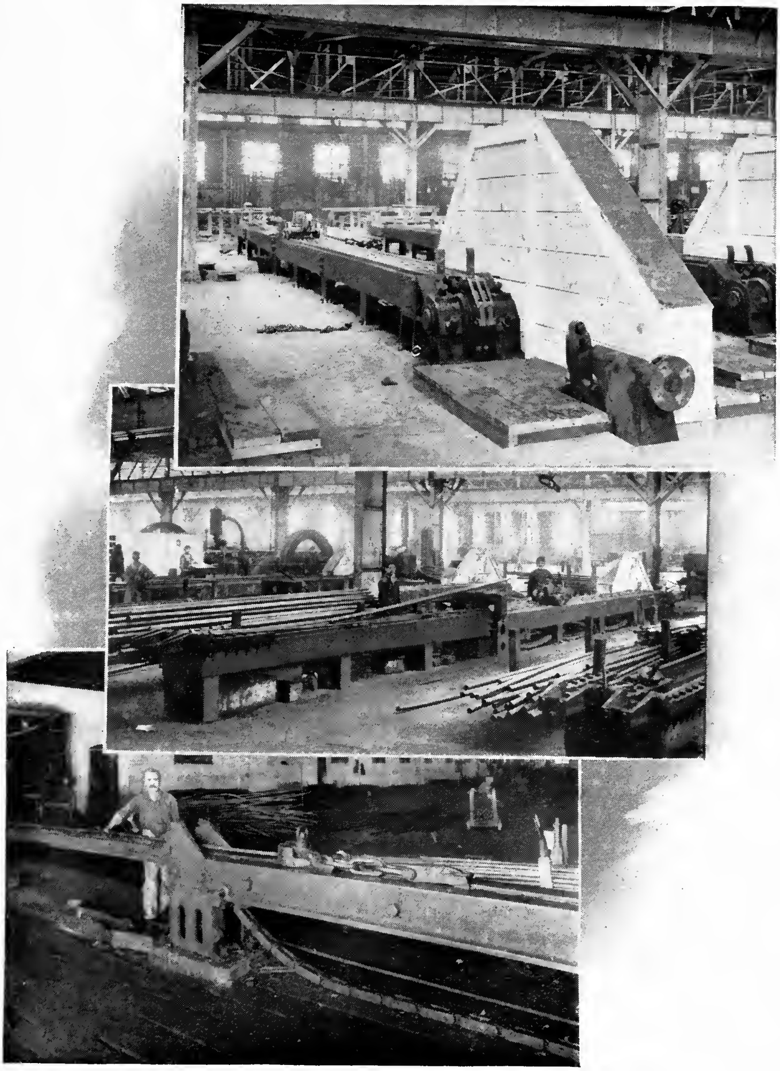


FIG. 71.—Three Views of a Cold-Draw Bench.

Annealing is not necessary, as the increase in its grain size is reduced by the constant working of the material after it left the furnace.

199. Cold-Drawn Tubes.—Tubes can be produced from 2 to 6 inches outside diameter by the hot finishing process. When necessary to produce (1) tubes of less than 2 inches diameter, or (2) larger tubes requiring the smoothest surfaces, or (3) tubes requiring greater accuracy in diameter and thickness of wall than can be produced by the hot process, this process must be followed by a series of cold drawing operations.

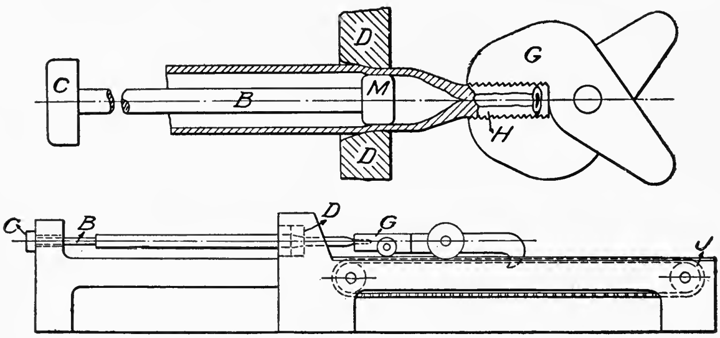


FIG. 72.—The Operation of Cold-Drawing Tubes.

These operations consist of drawing the hot-rolled tube through dies and over mandrels to reduce its diameters and thickness of wall.

The various steps in the cold drawing operations may be described as follows: The hot-rolled tube, after having cooled, is heated at one end and forged down to a rough point or tag, as shown at *H*, Fig. 72. After pointing, the tube is cleaned of dirt and scale by pickling in hot dilute sulphuric acid. It is washed in an alkali water to remove all traces of acid, and is then immersed in a lubricating vat. The lubricant consists of flour, water and tallow. After lubricating, the tube is taken to the cold-draw bench shown in the lower sketch of Fig. 72.*

* Fig. 71 shows three views of a cold-draw bench in the shop.

This machine consists of a frame arranged with a support for a die *D*, and is provided with a traveling chain or other means of moving a gripper or plier *G* away from the die. The other end of the machine forms a support for the end of the mandrel rod *B*. A die shown in cross section at *DD* of the upper view is placed in the die support. The pointed end of the tube is then pushed through the opening in the die and a cylindrical mandrel *M* on the end of the rod *B* is entered into the tube. A head *C* formed on the rod *B* engages with the frame of the bench, so that the mandrel and die are held rigidly in proper relation to each other as shown in the figure.

The opening in the die is smaller by from 1/8 inch to 1/2 inch than the diameter of the tube operated upon. The mandrel *M* is also smaller than the inside diameter of the tube, but to a slightly less degree than the die, so that the difference between the die and the mandrel size is less than the difference between the outside and inside diameters of the tube operated upon. The result is that in passing the tube through the die and over the mandrel, the diameter and wall thickness are simultaneously reduced.

The point of the tube having been placed through the die with the mandrel *M* in position, is gripped by the gripper *G*, which in turn is engaged by a hook with a moving chain *J*. The tube is pulled through the die and over the mandrel at the speed of the gripper. By this means, the sectional area of the tube is reduced about 15% for small tubes of light wall and up to 25% or to the strength of the bench for larger sizes. The drawing operation is repeated from 2 to 10 times until the desired diameter and wall thickness are obtained.

After each cold-drawing operation it is necessary to anneal the tube in order to soften it for the succeeding cold drawing. After annealing, the tube is pickled and lubricated as before. For many purposes the cold-drawn tube is used without annealing; but for purposes which require ductility in the material the tube is annealed at various degrees corresponding to the physical properties required. A temperature of 1200° F. removes all traces of the effect of cold drawing.

After receiving final operation, the tube is transferred to the finishing department where it is straightened and cut to length, inspected, gaged and tested and is then ready for shipment.

200. Brass and Copper Tubing.—The same methods of piercing and cold drawing described for making steel tubes are used to make tubes of copper and brass. Billets of brass are sometimes turned in a lathe to remove the rough outer surface before piercing.

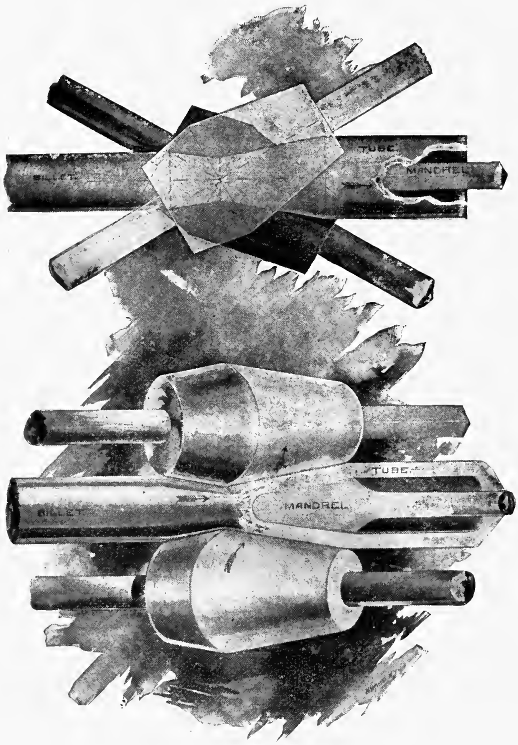


FIG. 73.—Mannesmann Piercing Rolls.

Fig. 73 shows plan and side views, partly in section, of a pair of Mannesmann rolls much used for piercing billets of copper and brass.

Brass pipe cannot be made by welding. It is made by piercing (or casting hollow) and then cold drawing. It is usually sent from the factory partially softened by annealing after drawing.

201. Tubes of Thin Walls and Small Diameters.—A tube may be cold drawn over a mandrel, as previously described, until its wall is too thin to stand further pulling through the die. If the tube wall is to be made thinner, further drawing is done by placing the tube over a solid steel arbor and drawing it down as shown in Fig. 74. The tension of drawing is then taken by the arbor and the tube wall may be drawn very thin. Large rigid arbors are pushed through the die. When the drawing is done, the tube is removed from the arbor by hammering it gently with a wooden mallet or by passing it between rolls.

Very small tubes are made without a mandrel. They are first cold drawn over a mandrel to a diameter of ½ inch or less and are then "sunk" by drawing through the die without a mandrel.

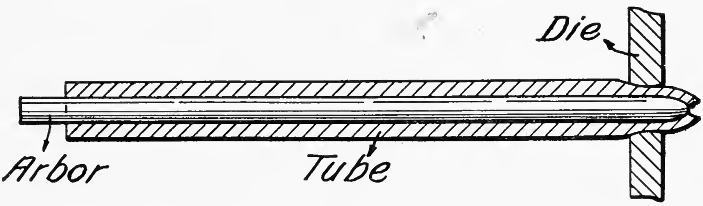


FIG. 74.—Arbor for Drawing Thin Tubes.

This reduces inside and outside diameters, but increases the thickness of wall. If the wall is to be very thin, an arbor is placed in the tube after it has been sunk nearly to the required inside diameter and the wall may then be drawn down as thin as required.

202. Defects in Seamless Tubes.

(1) *Snakes* are small surface cracks developed from surface cracks of the ingot. They are elongated in rolling, and are very small and hard to detect. They are more common in rolled plates than in tubes.

(2) *Laps* are thin fins of metal stretched and folded over the adjacent metal of the tube. They are caused in piercing.

(3) *Pits* are small depressions caused by over pickling or by rolling sand or scale into the tube surface.

(4) *Slivers* are tongue-shaped pieces of metal developed from blow holes or shrinkage cracks in the ingot.

(5) *Tears* are ragged openings in the tube surface caused inside by metal not passing freely over the mandrel at the draw bench, or caused outside by a rib of metal not passing evenly through the die. They are due many times to hard or weak spots in the metal.

(6) *Checks* are very small tears.

(7) *Rings* are transverse corrugations in the tube wall. They are caused by the jumping of the tube in drawing, due to poor bench equipment.

(8) *Sinks* are depressions extending around the inside of the tube. They are caused by a displaced mandrel, which allows the tube to draw to a smaller diameter than intended.

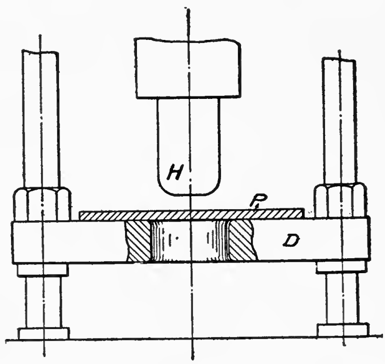


FIG. 75.—Making Hot-Drawn Tubes. Press for Cupping Discs.

(9) *Scratches* are due to rough dies and mandrels, to grit picked up by the tube after lubricating for drawing, or by insufficient lubricating.

203. Hot-Drawn Seamless Tubes.—For producing seamless tubes larger than 6 inches outside diameter, a hot drawing process is used. In this process a plate of the required thickness is punched or sheared into a circular disc. This disc is then heated to a bright red heat and placed in a hydraulic press arranged as in Fig. 75. The disc *P* is placed over the circular opening in the die block *D* of the press, and the plunger *H* is forced down on the plate, carrying it completely through the opening in the die block. The difference in the diameters of the openings of the die block *D* and the

plunger H is such as to give the sides of the cup the thickness of the disc. The squeeze between the plunger and the die block, as the disc passes through, presses the sides of the cup free from wrinkles. This operation is repeated with or without reheating until a cup is

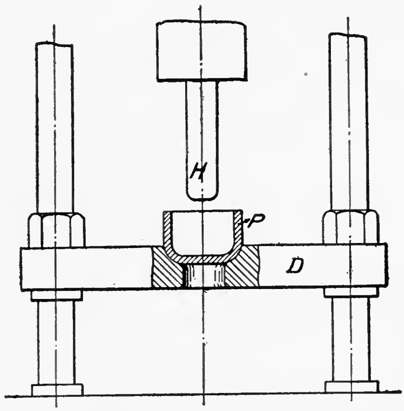


Fig. 76.—Making Hot-Drawn Tubes. Re-Drawing Cupped Discs.

produced of considerable length. The form of the die used in the succeeding operation is shown in Fig. 76. The die is recessed to receive and locate the cup produced by the previous operation and frequently the bottom of the cup is cooled by water to keep the plunger from punching a hole through it.

Fig. 77.—Cupped Discs.

The plate after receiving one or more cupping operations in vertical presses, is in a cupped form as shown in Fig. 77. Each cup is reheated and transferred for further reduction to a horizontal press usually called a hot-drawing bench, the essential features of

which are shown in Figs. 78 and 79. The bench consists of a heavy frame placed horizontally and connected to a hydraulic cylinder *C*. In operating, the cup *K* is placed over the end of the

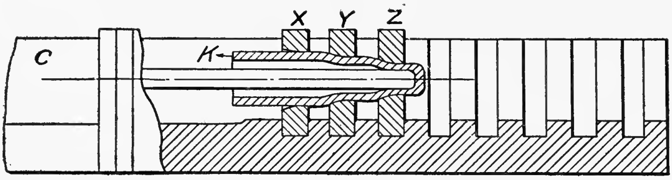


FIG. 78.—Hot-Draw Bench for Elongating Cupped Discs.

plunger rod, which is arranged to travel the entire length of the bench frame.

Dies *X*, *Y* and *Z*, with openings of successively smaller diameters, are placed in suitable holders in the bench frame. The cup *K* is

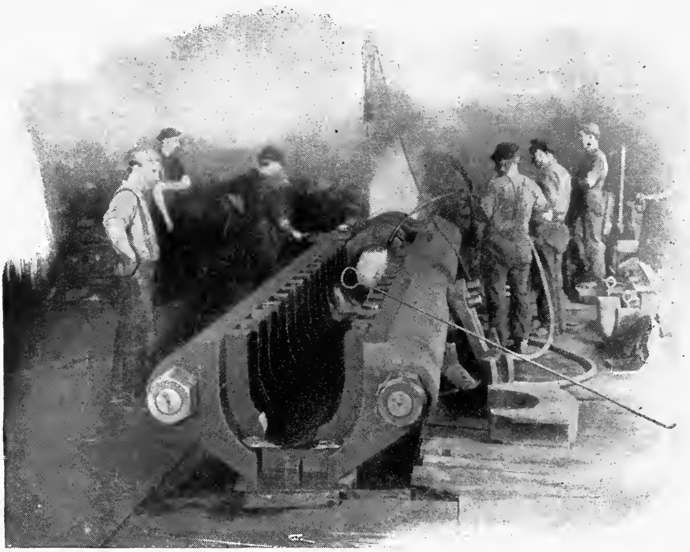


FIG. 79.—Hot-Draw Bench.

pushed through the dies successively as shown in the figure, reducing the diameters and the wall thickness. Several drawings are made in this manner, reheating between each operation until the tube is reduced to its final diameter and wall thickness. The

bottom of the cup is cooled with water from a hose to keep the plunger rod from punching a hole through it while the cup is passing through the dies.

After reducing the tube to its final diameter, the bottom is sawed off, the ragged edges of the open end are trimmed off, and the tube is then inspected and tested under hydrostatic pressure.

To show the change of form possible in hot drawing, a tube 22 feet long 9¼ inches inside and 10 inches outside diameter is made from a round plate 54 inches in diameter and 1¾ inches thick. This requires ten passes through as many different-sized dies.

Hot-drawn tubes may be further cold drawn to produce tubes up to ten inches in diameter.

204. Steel Cylinders for Storage of Gases.—From the hot-drawn steel tubes just described are made seamless-steel cylinders for

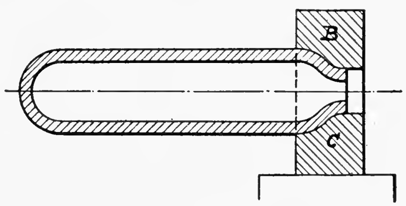


FIG. 80.—Reducing the Opening in a Hot-Drawn Tube

storage of gases under pressure. The bottom is left on the tube and the open end, after having had the defective part trimmed off, is heated and pressed under the dies *B* and *C* to a shape shown in Fig. 80. The opening is suitable for attaching a controlling valve to the cylinder.

These containers are made as large as 18 inches in diameter and 12 feet long.

Another method of closing the tube end is to hold the tube strongly in a rapidly revolving machine of great rigidity and bring the pressure of a steel roller against the side of the tube end. This pressure is so great that its friction heats the tube and closes it to the amount desired. The process is called *spinning* and may even be used to close and weld a tube end of mild steel.

205. Cold Pressing of Metals.—The ductility of many metals, including many of the alloys, is sufficient to allow sheets of the metals

to be pressed cold, without injury, into a great variety of forms. A considerable change of shape from the flat sheet may be accomplished by a succession of gradual changes, as was seen in forming large tubes in the operations of making hot-drawn tubes. The amount of distortion which can be accomplished at each step depends upon the power applied, and upon the ductility of the metal. The metal must be annealed after a certain degree of change of shape, else its ductility is lost and further pressure would disrupt the piece.

Common examples of the application of this process are cartridge cases, small round tin boxes, embossed metal ceilings, man-hole covers for boilers, metal ends of lead pencils, spoons, and many domestic utensils.

Many articles are pressed completely at one operation, and many others of more complicated shape are pressed in two or more successive operations under different dies, with or without annealing, according to the ductility of the metal used. This process is now applied to the shaping of articles from cold plates of mild steel as great as $5/8$ of an inch thick, although the thickness of steel which can be shaped cold is limited only by the power of the shaping press and the ductility of the steel.

The machines which shape thin sheets do their work by power transmitted through geared wheels, levers, cams, etc., to properly placed punches, dies and plungers, and the proper lubrication of the work is essential. These machines are built to turn out work with a minimum of attendance, and many of them carry a piece of metal through the several steps and turn out the finished product automatically so long as sheet metal is fed to them.

The shaping of heavier sheets, particularly those of steel, usually requires hydraulic presses, although very powerful machines are built for heavy work similar in design to those for lighter work.

As with all metal-shaping processes, particularly do these processes require means of holding the metal to be shaped firmly in the position or positions required.

206. Steps in Shaping Articles from Sheet Metals.—Fig. 81 shows the steps in the process of shaping a vessel from tin, brass, copper or other sheet metal. The first step is to stamp out the disc, No. 1,

from the flat sheet, called *cutting* or *blanking*. The *shapes* 2, 3 and 4 are then successively stamped between upper and lower dies which are counterparts of these shapes. This kind of shaping is

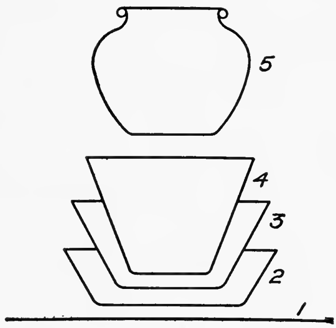


FIG. 81.—Steps in Shaping Sheet Metal by Drawing and Spinning.

known as *drawing*. Shape 5 is produced by *spinning,* and is done on a type of lathe shown in Fig. 82. A solid shaping roll of the contour of the work is held inside the shape as it revolves, and the

FIG. 82.—Spinning Lathe.

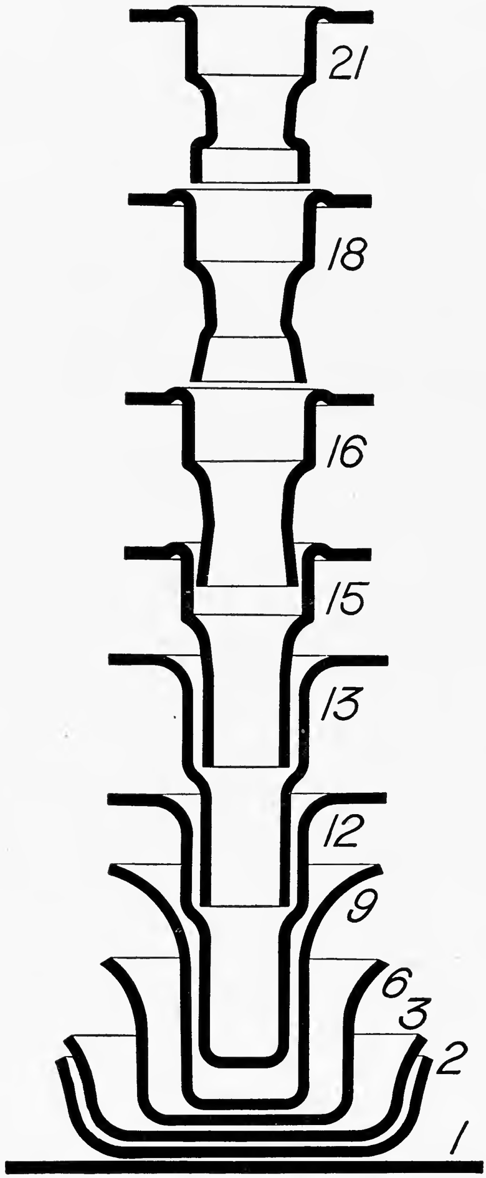


FIG. 83.—Steps in Pressing a Vehicle Hub from Steel Plate.

spinning is done from the outside by pressure of a burnishing roll mounted on the lathe carriage.

Any embossing or lettering raised from the surface of the metal is done by *stamping.*

Cylindrical metal boxes several inches long and less than half an inch in diameter, can readily be formed from discs of sheet metal by this process.

Another example of cold pressing is shown in Fig. 83. This shows the gradual changes of form in shaping a vehicle hub from a steel disc $3/8$ inch thick and 15 inches in diameter. The flange of the finished hub is $7\frac{1}{2}$ inches in diameter. The steps are numbered consecutively. Annealing is necessary after about each third step, judged by the workmen for each piece.

207. Drop Forgings.—The process of forging small articles of iron on the blacksmith's anvil is well known. Hand work of this kind is very expensive for making intricate shapes and is a slow process even for making simple shapes. Various processes have been employed to shape iron articles in quantity which will be at least as good in quality and less expensive than forgings made by hand. One of the processes so employed is drop forging. By this means, a great variety of forgings of plain and intricate shapes can be produced in large quantities far cheaper and possibly better than by means of hand forging. Drop forgings must be needed in large quantities to warrant making a pair of dies, as these are expensive.

A drop forging is made by the drop of a heavy hammer on a piece of hot iron held by a workman on the anvil of the machine. The hammer carries a die which shapes the upper half of the forging, and the anvil holds another die which shapes the lower half.

FIG. 84.—Drop Hammer.

208. The Drop Hammer.—Fig. 84 shows a type of drop hammer such as is used for making drop forgings. The lower die is held on the anvil *A* and the upper die is held under the hammer *B*, by keys in the dovetails shown. The dies are not shown in this view. The uprights of the machine form guides between which the hammer is raised and dropped. The hammer is raised by a smooth board which passes between two cylindrical rollers at the top or "head" of the machine. One of these rollers is marked *C*. Each roller is driven by its own shaft and belt wheel. The two belt wheels are marked *WW*. The bearings of the roller shafts are arranged so that the rollers may be made to grip the board or may be separated to allow the board to drop between them. This adjustment of the rollers is controlled by the rod *D*, connected to the foot lever *G*. The workman may instantly release the pressure of the rollers on the board and cause the hammer to drop, without checking the speed of the rollers themselves. A lever *H*, shown in front of the machine, is arranged to trip the hammer automatically so that it may not go too high.

The hammer weighs 1000 lbs. or more, and it takes but a few strokes to forge a considerable mass of iron into shape.

209. Drop-Forging Dies. Making a Drop Forging.—Dies for drop forgings are made of hardened forged steel, of cast steel or, for roughing out large work, they are made of chilled cast iron. Dies are made in pairs, as shown in Fig. 85. The lower contains an impression of the lower part of the forging, and the upper contains an impression of the upper part. For some forgings the face of the die contains a rough and a smooth impression of the forging.

The dies in Fig. 85 are used as follows: A bar of iron of convenient length for handling and of sufficient cross section to fill the dies is heated in a small oil or gas furnace nearby. The first operation is to place the end of the heated bar along the lower die over the impression *B* and give it one or more blows with the hammer to shape it roughly to the outline of the forging to be made. This is called breaking down, and the impression at the opposite edge of the dies is also used to assist in this work. This operation is immediately followed by placing the broken-down end over the die *D* and dropping the hammer on it, usually about twice. The metal is forced into both dies, completely filling them, and the surplus metal is forced into the slight depression surrounding the dies. But

for this depression, the dies could not come together and the forging would be too thick. The fin or "flash" of metal thus formed around the forging is shown on the wrenches marked *F*. The flash is cut off in another machine called the *trimming press* which stands alongside the drop hammer. The finished wrenches are shown at *G*.

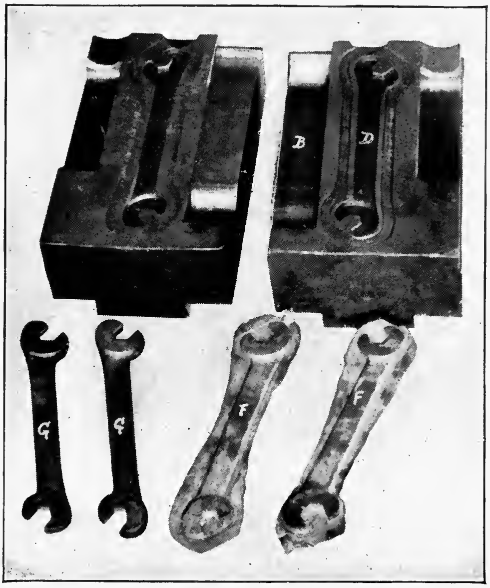


FIG. 85.—Drop-Forging Dies and Specimens of Work.

To keep from cutting off the end of the bar in process of being forged, and leaving the forging with no holding piece, a notch is cut in one end of each die as shown at the ends of the wrench dies. A cutter at the side of the die usually cuts off a forging when shaped as shown at *F*. Frequently forgings are pickled to remove the forge scale before trimming off the flash. Large forgings and high-grade small forgings are annealed.

Fig. 86 shows a pair of dies *B, B,* for an automobile engine crank-shaft, and *C, C,* show the two parts of the trimming dies.

Fig. 87 shows the steps of shaping the crank shaft from the bar *a*. A few blows of the hammer break it down at the side of the die to the shape *b*, and then the die shapes it in about a dozen strokes as at *c*.

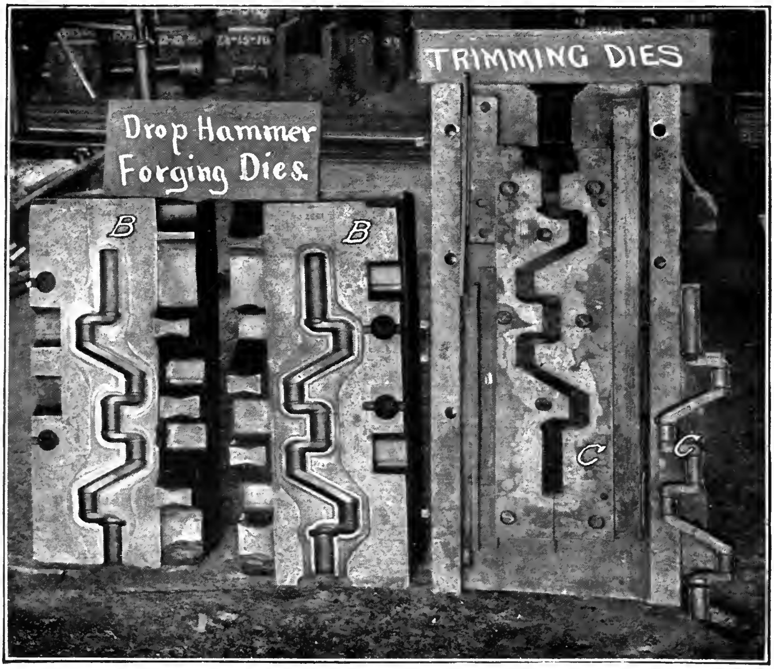


FIG. 86.—Dies for Forging and Trimming a Small Crank Shaft.

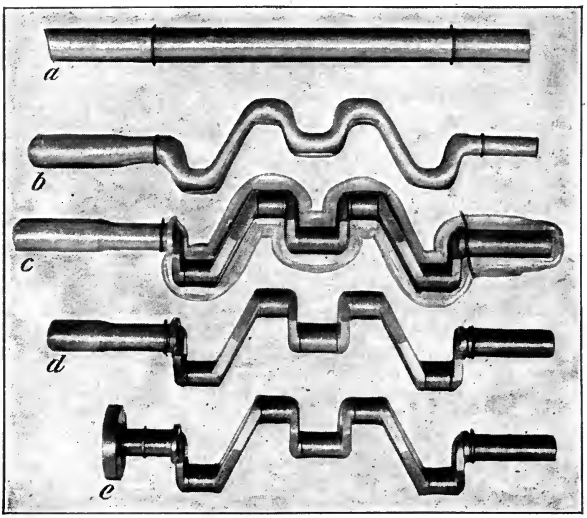


FIG. 87.—Steps in Forging an Automobile Crank Shaft.

The trimming press, in which are mounted the dies *C, C,* cuts off the flash as at *d,* and the bull-dozer or upsetting press presses a flange on the end *e* after a reheating.

FIG. 88.—Specimens of Drop Forgings.

After annealing, the forging is ready for machining to its required dimensions.

Fig. 88 shows a number of specimens of drop forgings, and Fig.

89 shows a high-grade alloy crucible-steel forging twisted and bent cold to show its quality.

Long forgings are forged one end at a time to avoid making an unduly long die and having to handle an unwieldly piece of work. An automobile axle is about the longest drop forging made.

FIG. 89.—A High-Grade Drop Forging Bent and Twisted Cold.

210. Bolts, Nuts and Rivets.—Bolts, rivets and nails are pressed into shape, and nuts are punched, by machines specially built for this work.

Fig. 90 shows the general arrangement of a machine for pressing bolts, rivets and wire nails. The end of a coil of wire or rod *R* is fed by two or more pairs of grooved roller wheels through a guide

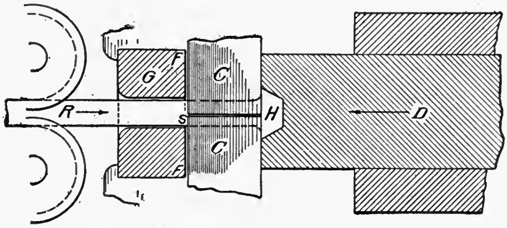


FIG. 90.—Rivet-Pressing Machine.

G. When the end is far enough through, the feeding wheels stop and the two clamps *CC* close together and grip the material firmly. The die *D* then moves forward through its guide, in the direction of the arrow, presses the head *H* into shape, and then moves back. The clamps *CC*, release their hold, move back, a cutter moves along the face *FS* of the guide *G* and shears the rivet from the rod at *S*, and it falls into the box under the machine. When the cutter

has moved out of the way, the feeding wheels again revolve, the material is fed in, and the operation is repeated.

The die *D* may be replaced by others to give different shaped heads (for nails or bolts).

The clamps *C* may take part in the shaping, as in pressing barbs on the body of a nail, in addition to performing their work of gripping and holding.

Rivets and rough bolts up to 5/8-inch diameter may be pressed cold from soft-steel material. If hot material is fed into the machine, it is in the form of straight bars and not in coils. Only a few feet of the bar is heated and when this is used up by the machine, the remaining end is then heated.

Boiler rivets and the better grades of bolts are hot pressed. Sometimes they are cut to length before heating for pressing, and the head may be pressed in two heats. This is done in high-grade work. Boiler rivets are always annealed after they are formed.

Bolts are often cut from rods of solid metal in bolt-cutting machines.

Square and hexagonal nuts are pressed, punched, and sheared from long, flat bars. Nuts are also cut by machines from bars of square or hexagonal cross sections.

211. Screw-Cutting Machines.—These are machines of ingenious design which make a great variety of small metal objects from round, square, hexagon or other shaped rods of brass, bronze and steel. They embody a very high degree of mechanical ingenuity, and the rapidity and accuracy with which they turn out a superior grade of work is remarkable. Not only do they make all kinds of machine and other screws, particularly in medium and small sizes, but they make an endless variety of small articles too thick or intricate to be made by the drawing and spinning processes mentioned for shaping sheet metals.

Fig. 91 shows an automatic screw machine. It is so equipped and geared that when a rod of metal, usually about 16 feet long, is placed through the main spindle at *B,* and the machine started, it continues work unattended until the rod is entirely cut into articles which the machine is at the time set to produce.

The rod is gripped by a small chuck *C,* with enough of the rod end extending beyond the chuck to be operated upon by the various

cutters. Most of the cutters are mounted on a small turret *T*, the axis of which is horizontal and at right angles to the axis of the spindle. The shaft which carries the turret is mounted on a carriage *D* which can slide back and forth parallel to the direction of the spindle axis. The whole mechanism is so geared together that the part of the rod extending beyond the chuck is operated on successively by each of the six tools clamped on the turret and re-

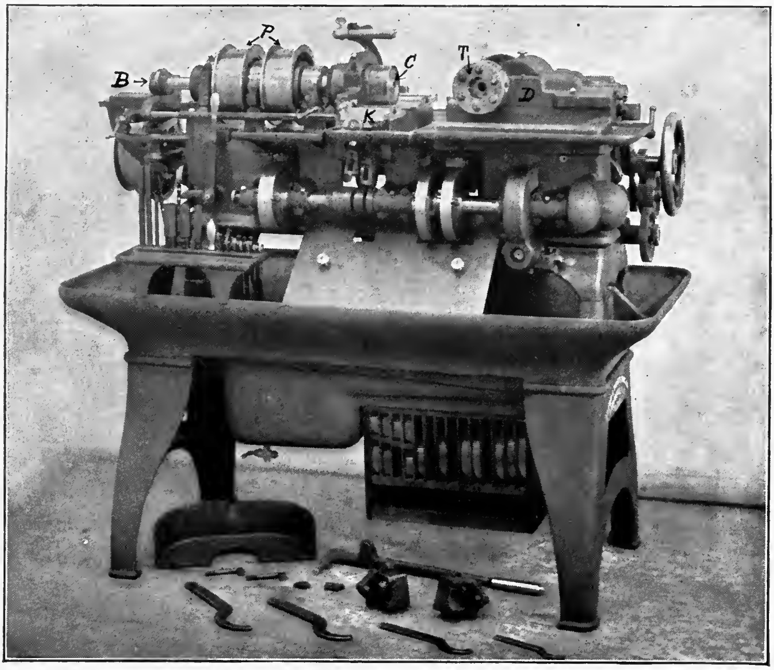


Fig. 91.—Automatic Screw-Cutting Machine.

volved into place at the proper time. In this way the accumulated cutting of the several tools on the rod end, each tool doing its particular part of the cutting, shapes the pieces as required. When so shaped, a cutter cuts the piece off the rod end, and it falls into a box below. The rod is then automatically fed in a definite amount for the cutting operations to be repeated.

The machine has an attachment, not here shown, for cutting a screw driver slot in the head of a screw after it is cut from the rod.

212. Examples of Work from the Screw Machine.—Fig. 92 shows a variety of small articles made on screw machines. The sizes of these articles vary in length from a fraction of an inch to

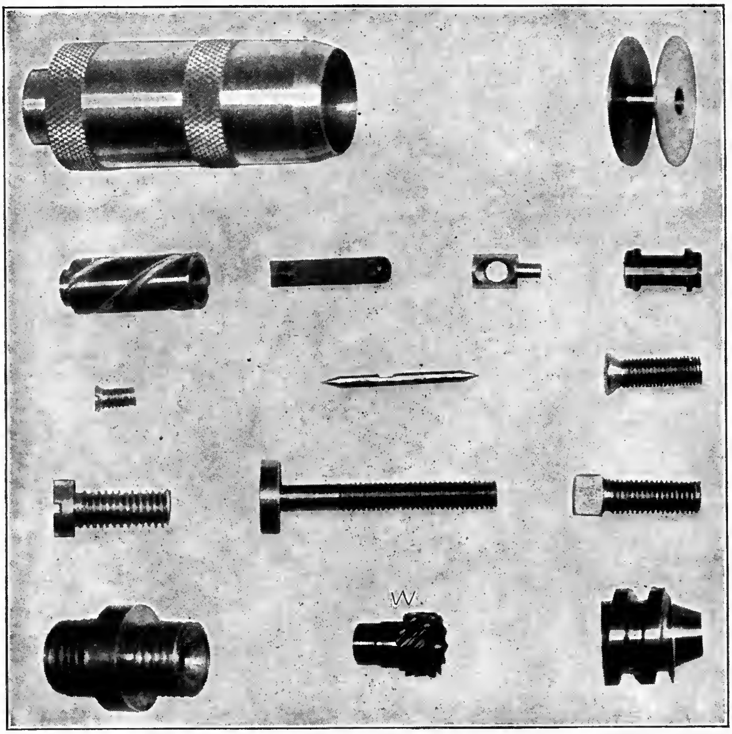


FIG. 92.—Products of the Automatic Screw Machine.

more than two inches. The specimens shown are pointed to the right the same as they were held in the machine during the process of making.*

* Paragraph 439 of the Appendix outlines the work of cutting the piece *W* of Fig. 92.

CHAPTER VII.

SHOPS OF MACHINERY BUILDING AND REPAIRING PLANTS. DRAWINGS FOR SHOP USE.

213. Distinctive Features of Building and Repairing Plants.— The building of ships, engines, locomotives, machine tools and large machines for a great diversity of purposes necessitates bringing together the products of several different shops. While each of these shops considered alone is virtually a place for the re-manufacture of metals along its own particular lines, the assembled products of the several shops present such a diversity of construction and each machine or structure so built has so distinctive an identity of its own, that an establishment made up of an assemblage of such shops is regarded as beyond the limitations of a re-manufacturing plant.

For example, a ship or a locomotive is a much more distinctive product than the plates, castings, bolts, rivets, pipes, etc., which compose it, and the assemblage in one establishment of the different metal-working shops required to build either embodies the capacity for turning out, quite as readily, machines or structures of many other kinds.

Assemblages of shops capable of uniting such a diversity of rolling mill and re-manufactured products into highly complex constructions are also most advantageously fitted as general repair shops, and particularly, because of its accessibility, is a shipbuilding plant also an extensive ship-repairing plant.

214. Shops Composing a Building and Repairing Plant.—The important shops of a large building and repairing plant are:

(1) The Woodworking shop, including the Pattern and the Joiner shops, sometimes separate.

(2) The Foundry.

(3) The Blacksmith or Forge shop.

(4) The Machine shop.

(5) The Boiler shop.

(6) The Copper and Sheet Metal shop, sometimes divided into two shops.

(7) The Plate and Angle shop, for shipyards and, to a less extent, for bridge material plants.

Of prime importance to any manufacturing plant is the drafting room, or drawing room, in which the design of machinery parts is worked out and drawings of these parts are made to guide the several shops in shaping their respective parts for the complete machine. In a ship-building plant the drawings of the ship's hull are elaborated by scribing them out to full size on the floor of the mould loft as the best means of obtaining the exact form of the various individual frames and plates of which the hull is composed.

A very essential adjunct to the machine shop is the erecting shop, where the finished parts of a machine are assembled and secured together as a complete unit. All engines and large machines are thus assembled and tried, after which they are dismantled and moved away.

Of indispensable importance in metal producing and many metal shaping establishments are (a) the chemical laboratory for analyzing materials, (b) the testing room, for testing the strength of materials, and (c) the inspecting department for inspecting and testing finished products.

215. The Drawing Room.—When a designer has determined upon the action, position, form and material of each part of a machine, his ideas are sent to the drawing room in one or more sketches. From these an assembled drawing is made of the whole machine, to a definite scale, and by aid of the sketches and the assembled drawing, detail drawings are made in larger scale, convenient for showing the details of each part and for recording the dimensions.

In the design of a ship, bridge, structure or machine of any kind, the kind and quality of materials to be used must be determined by

the designer, who must also determine the size and shape of each part with a view to giving it the required strength.

216. Drawing-Room Methods.—Assembled and detail drawings are first made in pencil on a quality of heavy white or straw-colored paper which will stand considerable erasing. A sheet of tracing cloth is placed over this work, when completed, and the work copied, or traced, in ink. The tracing is then used for making blue prints or black prints and is kept on file in the drawing room. Many drawing rooms are provided with a fire and water-proof vault for the safe keeping of valuable tracings.

217. Shop Drawings.—The shops must be supplied with drawings of any piece of machinery to be made, as guides to the workmen. These drawings are usually blue or black prints made from the tracings, as mentioned in the preceding paragraph.

The information in the following items should be shown by a drawing:

(1) One or more views of the article, amplified by cross-section views where needed, to show fully its form.

(2) Dimensions sufficient to make the article to the exact size required, and sufficient to save the workman the necessity of adding several dimensions to find another dimension.

(3) Designation of the material or materials of which the piece is to be made.

(4) Designation of the number of pieces required.

(5) Indications of any special features of material, finish, or changes from usual conditions.

(6) The scale to which the drawing is made, or the designation of the scale of each of the parts if they are drawn to different scales on the same drawing.

(7) The title and number of the drawing, giving names and uses of the parts shown, date of authorization and name of authority approving the drawing, and, if the drawing supersedes another drawing, a statement to this effect, giving name, date and number of superseded drawing.

218. Methods of Representing Articles on Drawings.—Figures 93 and 94 are examples of two methods of showing an article on a drawing. The former is the *orthographic* method which shows three views projected upon three planes of reference as used in descriptive geometry, and the latter is the *isometric* method, used particularly in free-hand sketches and now used on finished drawings.

In many cases, two orthographic views will show fully the details of an article, particularly if one is a cross-section view. Simple articles may be shown by one view. In Fig. 94 the isometric axes AB, AC and AD are 120° apart, that is, the angles CAD, DAB and CAB are 120°, with AB vertical.

219. Consecutive Order of Shop Work.—It is a part of the work of the designer of any mechanical structure or machine to determine not only the material of which each piece of the structure is to be made, but the general method of making it, which necessarily includes a designation of the shops in which the work is to be done.

If an article is to be shaped in cast iron, cast steel, or other cast metal, a pattern, usually of wood, must first be made in the pattern shop. This is made according to dimensions and other information given on the drawing. This pattern is used in the foundry as a model for a mould, which, when prepared, is poured with molten metal. The piece thus cast more or less roughly, is cleaned and used sometimes without further work upon it, but if accurate fitting and exact dimensions are necessary for the casting, it goes to the machine shop to be machined, and possibly ground if very accurate fitting is needed.

If the article is to be made as a forging, a bloom, billet, or smaller piece from the rolling-mill stock kept on hand is forged to the required shape either by hand or by steam hammer in the blacksmith shop, and the forging may, in some cases, be used just as it comes from the anvil, or, if it must be finished to particular shape and dimensions, it goes to the machine shop.

Many articles may be made in the machine shop directly from rods, bars, plates and shapes from the rolling mill, without having been given preliminary form in the foundry or the blacksmith shop.

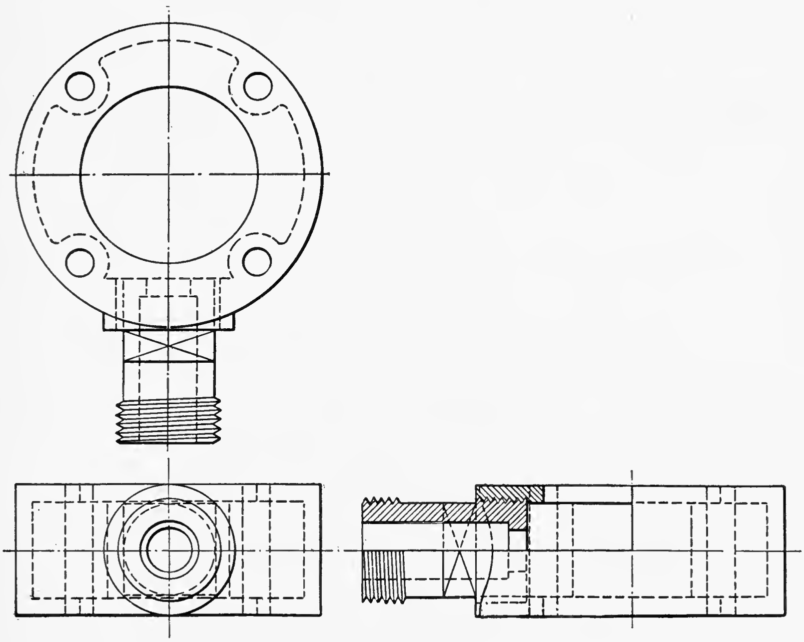


FIG. 93.—Orthographic Projections.

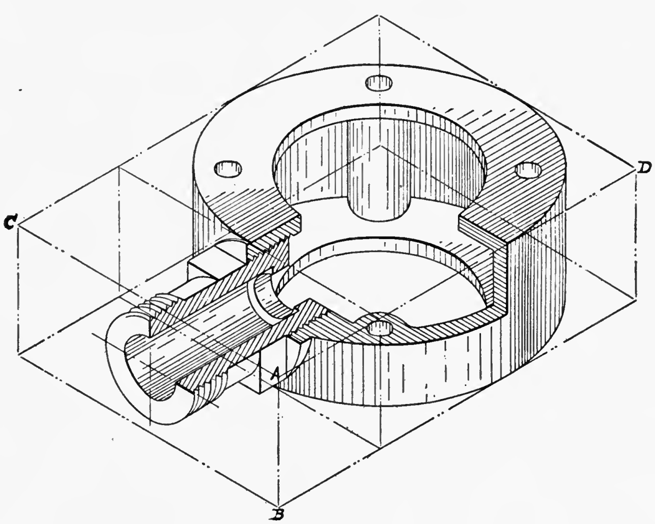


FIG. 94.—Isometric Projection.

The boiler shop works into shape plates, sheets, tubes, etc., direct from the rolling mill, and fittings produced in other shops.

The copper and sheet-metal shop draws its sheet material direct from the rolling mill. Much copper and brass tubing, obtained from the tube mills, is used in the copper shop.

The plate and angle shop uses plates and structural shapes supplied direct from the rolling mills.

All shops of building and repairing plants find more or less use for bolts, rivets, screws, and various other products of the remanufacturing industries in connection with their own shop products.

CHAPTER VIII.

THE PATTERN SHOP.

220. Work of the Pattern Shop.—This shop is a woodworking shop devoted to the making of wood patterns for the foundry. These patterns are used as models for shaping moulds of articles to be cast from molten metals.

A pattern maker must be an expert woodworker, and must be skilled in reading correctly the most intricate mechanical drawings. He must also be versed in the methods used by the foundryman in making moulds, to know how to make patterns in forms best suited to foundry requirements yet not unnecessarily costly.

Cabinet making and joiner work may be done by pattern makers with pattern-shop equipment, but in large ship and machine-building establishments, the pattern shop and joiner shop are usually separate.

221. Pattern-Shop Equipment.—The woodworking appliances which compose the pattern-shop equipment may be divided into (1) power tools (machine tools driven by power), (2) hand tools, and (3) accessory appliances such as work benches, clamps, glue pots, etc.

222. Power Tools.—Machines of this kind are, in all kinds of shops, labor-saving devices. While many such machines might be omitted from a shop equipment, the time and cost for turning out work without them would be greater than if the machine were used, and in many cases hand work would be less accurate.

The usual power-tool equipment of pattern shop includes:

(1) Circular saw.
(2) Wood lathes, usually large and small sizes.
(3) Face lathe.
(4) Band saw.
(5) Hand planer, or jointer.
(6) Surface planer.
(7) Boring machine.
(8) Mortise machine.
(9) Scroll saw.

(10) Emery wheel.

(11) Grind stone.

The variety and quantity of work to be done in a shop determine its power-tool equipment, hence in many small shops some of the tools of the foregoing list may be omitted, while in the most extensively equipped shops some special tools not here named may be installed.

223. The Circular Saw.—Fig. 95 shows a type of circular-sawing machine such as is used for pattern-shop work. This machine con-

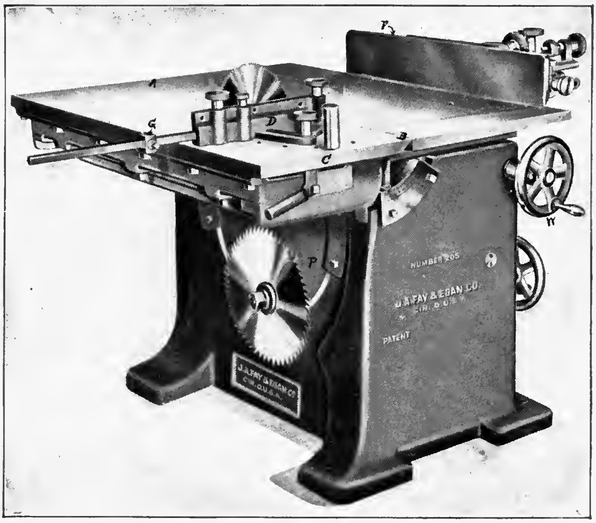


FIG. 95.—Circular Saw.

sists essentially of (1) a frame which carries the saws, saw mechanism and table; (2) a flat-topped saw table of ribbed cast iron, and (3) one or two saws mounted ready for use.

The saw table is made in two sections, divided along AB. Both sections always remain in the same plane relative to each other, but the part C is mounted on suitable slides on which it may be moved back and forth in the direction AB parallel to the plane of the saw. Small work to be sawed is held by hand against the guide or "fence" D which may be set so that the end of the piece of work will be cut off at any angle desired as the movable table carries

it past the saw. The block *G* may be adjusted along the stop rod for gaging the length to which pieces are sawed.

When the machine is used for ripping boards into narrower widths, the ripping fence *F* is set as a guide at the distance from the saw necessary for cutting the widths required. Ripping, or sawing along the grain of wood, is done by the coarse-toothed saw for more rapid working.

While the upper saw is in use, the belt which drives the saws is not in contact with the belt wheel of the lower saw, hence this saw

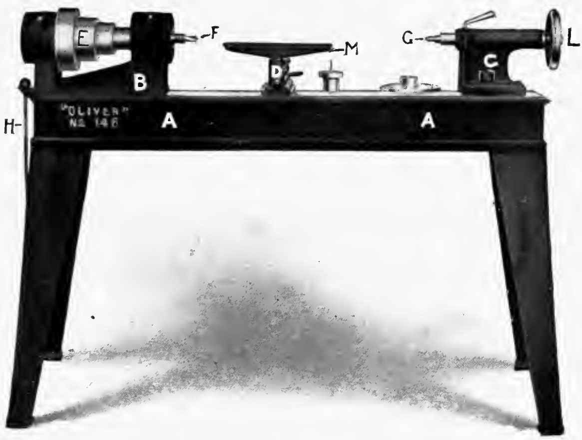


FIG. 96.—Woodworking Lathe.

is idle. When the lower saw is to be used, it is revolved into position by turning the wheel *W* while the machine is not running, and as one saw is carried into position for use, the other is simultaneously carried below the table.

The saw table may be tilted about *AB* as an axis for sawing at an angle. The saws should run at about 600 revolutions per minute.

224. The Speed Lathe.—This is the common designation for a small wood-turning lathe, which turns at high speed. As the cutting is done by hand tools, this lathe is sometimes called a hand lathe. Fig. 96 shows a view of this lathe. Its main parts are: *A,* Bed; *B,* Head stock; *C,* Tail stock; *D,* Tool-rest holder.

Work is held in the lathe between the live center F and the dead center G, or the live center is punched out by means of the rod H and the work is fastened by screws to the face K, shown in Fig. 97. As the work revolves it is shaped by hand tools steadied on the tool

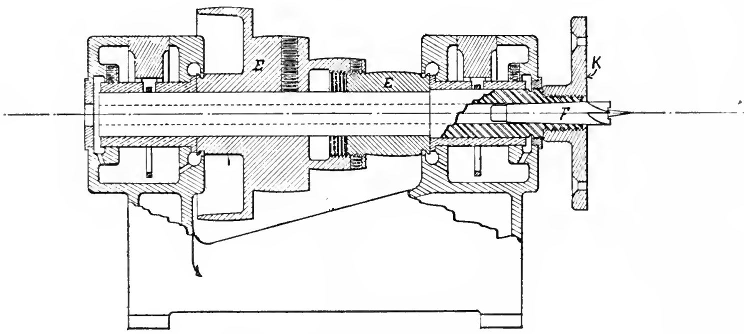


FIG. 97.—Lathe Headstock.

rest M. The live center drives the work when it is suspended between centers.

The head stock carries a hollow steel spindle which is made to revolve at different speeds by a belt on one of the cone pulleys E. Fig. 97 shows a cross section of the moving parts of the head stock.

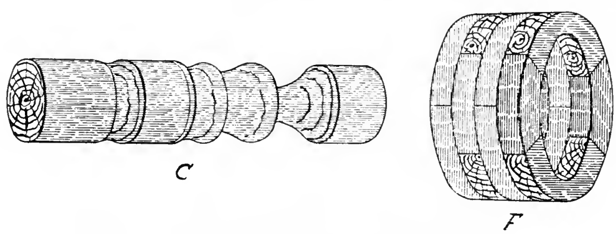


FIG. 98.—Specimens of Wood-Lathe Work.

Fig. 98 shows two examples of work turned in this lathe. The piece C is held between centers and the piece F is held only on the face plate.

The tail stock may be moved along the lathe bed to suit the length of work, and when it is clamped to the bed, the dead center may be moved back and forth by turning the wheel L.

These lathes are used not only for turning wood, but are adopted to finishing articles of metal after they have been roughed to shape in a machine lathe. For hand turning of metals, different tools are used from those for turning wood.

The *swing* of a lathe is the diameter of work which can revolve freely between the centers and the lathe bed or its attachments. The *distance between centers* is the length of work which may be held between the lathe centers. These definitions apply to all classes of lathes, in either pattern or machine shop, and are the measurements by which the sizes of lathes are designated.

FIG. 99.—Turning Tools for Wood Lathes.

225. Turning Tools.—Fig. 99 shows the turning tools ordinarily used with wood lathes. Naming from *left* to *right* they are:

(1) Round-nose chisel.
(2) Flat scraping chisel.
(3) Gouge.
(4) Diamond-point chisel.
(5) Skew chisel.
(6) Double-end skew chisel.
(7) Combination roughing and smoothing chisel.

Numbers 6 and 7 are used only on larger size lathes, and are clamped in a tool holder. Fig. 100 shows a tool holder which may be used on small or large lathes. It is at present rigged for holding hand tools.

226. The Wood Lathe.—This designation is given to the pattern-shop lathe for turning large work.

It embodies the same features as the small lathe, and is operated in the same way. Hand tools may be used for cutting, or a heavier

tool may be clamped in the tool post which holds the bar of the hand-tool holder shown in Fig. 100.

Most large lathes are equipped with a movable tool carriage in place of the tool-rest holder, which moves by hand or by power

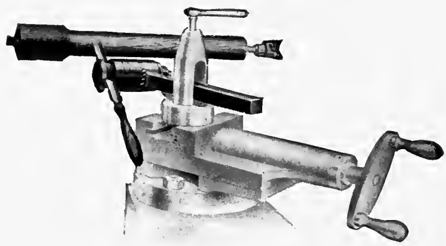


FIG. 100.—Tool Holder.

feed along the lathe bed. The view in Fig. 100 shows the upper part of a carriage of a large lathe.

227. The Face Lathe.—This lathe consists merely of a head stock mounted for carrying a large face plate. It is used for turn-

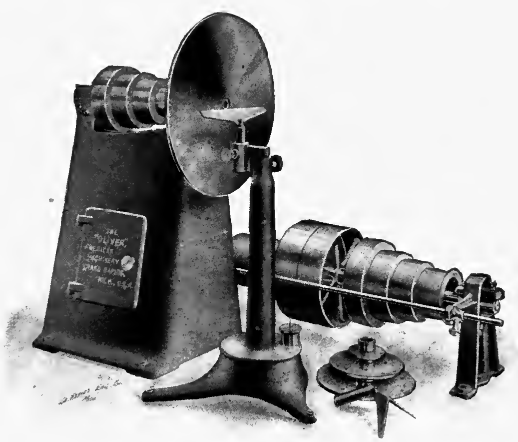


FIG. 101.—Face Lathe.

ing flat work of large diameter. This type of lathe is shown in Fig. 101.

228. The Band Saw.—This machine is shown in Fig. 102. It is used for sawing along straight or curved lines, and may be used for

light or heavy work, according to the size of the saw on the machine. Several saws are provided. They are endless steel bands with teeth along one edge.

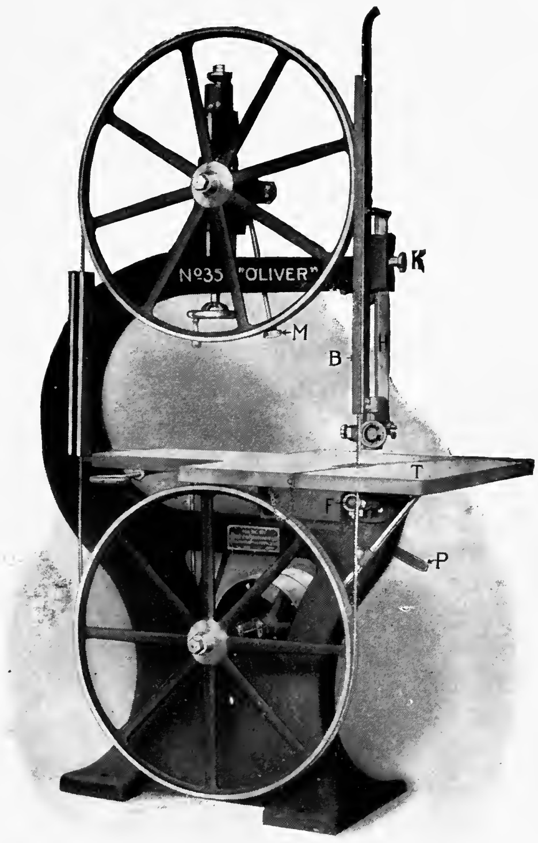


FIG. 102.—Band Saw.

Work is placed on the table T. The saw, which is carried on two large rubber-tired wheels, moves through a slit in the table, and is driven by the lower wheel.

For most work, the table T is perpendicular to the path of the saw, but the table may be tilted about the slot as a horizontal axis, for sawing at an angle, and is clamped by the handle P.

To prevent the saw being pushed gradually off the wheels by the pressure of the work against it, the back edge rubs against two guides, the upper of which is carried by a stem *H* which may be raised or lowered to suit various thicknesses of work, and which is clamped in position by the handle *K*. The saw is kept taut over both wheels, which are kept in the same plane by the tilting screw *M*.

It is well to note that the more recent designs of all classes of machines in all shops are provided with guards and protectors to

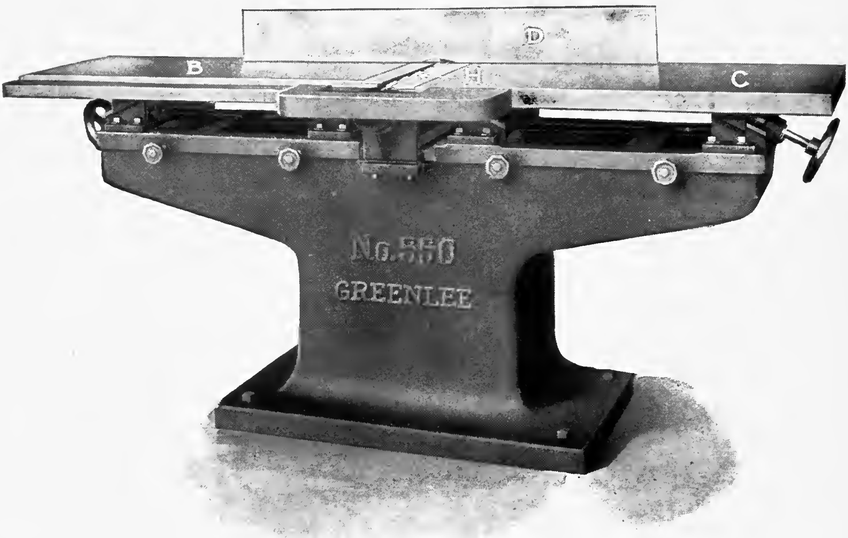


FIG. 103.—Hand Planer.

protect workmen from injury. The saw here described is guarded by casing not shown in the figure. Many machines are provided with means for stopping them automatically in case of accident.

229. The Hand Planer.—This machine, shown in Fig. 103, is also known as a *jointer*. It is used to cut the face or edge of a board to a plane surface, to chamfer corners, to gain, check, plow, match, etc. Board edges and parts of patterns are cut true in this machine to enable them to fit closely together for gluing. This machine does the work of a man with a hand plane, and is best adapted to small work which may be easily lifted and handled.

The machine consists essentially of a base, on which is mounted two flat tables *B* and *C*, one slightly higher than the other, a cutter head *H*, and a "fence" *D* which serves as a guide for the work.

Either table may be raised or lowered a small amount to regulate the cut of the knives carried by the cutter head, and may be moved horizontally to or from the cutter head to give ample clearance for the knives and for shavings. The work to be planed is pushed along on the table by hand over the rapidly revolving cutter head, the two knives of which are set to take equal depths of cut from the under surface of the wood. The cutter head consists of a steel cylinder slotted for holding the two long knives which are held in place by small screws.

Many forms of grooves may be cut by setting in one of the knife slots a knife with its edge of the required contour.

230. The Surface Planer.—This machine is constructed with the same method of cutting provided for the hand planer, but it is a much heavier machine, and is used for surfacing rough boards and timbers. Its table is made in one flat piece fitted to be raised or lowered readily to suit the thickness of the board or timber passing under the knives. The work, resting on the table, passes under the cutter head, also it passes under rollers which hold it down before and after it reaches the cutter head. These rollers feed the work along the table.

231. The Boring Machine.—This machine is used for boring holes, and consists essentially of a round spindle held horizontally or vertically in suitable bearings. The spindle carries a bit or auger and is made to revolve rapidly. The work to be bored is placed on a suitable stand and remains stationary while the spindle moves in the direction of its length as it revolves, until the bit cuts into the material to the desired depth. In some designs of this machine the spindle merely revolves and the material is fed against the bit.

232. The Mortise Machine.—This machine is used to cut square or rectangular holes in wood. It consists essentially of a vertical shaft which is made to oscillate in the direction of its length, and which carries a heavy chisel at the lower end. Mortising machines are often worked by the pressure of the foot, without machine power.

233. Hand Tools.—The hand tools of pattern making are more or less familiar as those used in carpentry work. Attention will be called to a few special tools and features.

Saw Teeth.—In sharpening saw teeth, the file should be held at an angle to the plane of the saw blade so that the teeth will present an appearance shown in Fig. 104. The teeth should also be "set" to keep the wood from binding the sides of the saw. This is done by bending the teeth marked *c* slightly to one side of

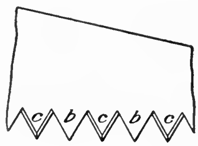


FIG. 104.

the plane of the saw, and by bending those marked *b* slightly to the other side. In this way the saw cut is slightly wider than the blade thickness of the saw.

The teeth of circular saws may be "set" or may be "swaged." In swaging, the teeth are not bent to one side, but the tooth end is expanded by a swage and hammer so that its cut is wider than the thickness of the saw.

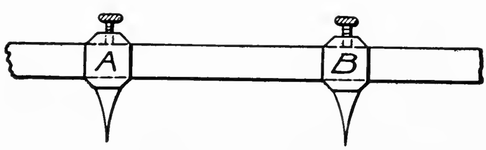


FIG. 105.—Trammel Points.

Trammel Points.—For describing arcs of large radii, a pair of trammel points, *A* and *B*, are mounted on a bar of wood or metal as shown in Fig. 105. These points may be clamped at any position along the bar.

Wood Trimmer.—A very useful pattern-shop tool is the wood trimmer, shown in Fig. 106. This machine is much used to cut ends of wood pieces to an exact angle (usually square) with the face or edge of the piece. It consists essentially of a flat table *B* along the rear edge of which slides a triangular-shaped piece, carry-

ing two knives *C* and *D*. The plane of these knives is exactly 90° to the plane of the table. The guide pieces *F* and *G* have their faces perpendicular to the plane of the table, and they may be swung around on vertical axes and clamped at any desired angle to the plane of the knives. A piece of work to be cut is held securely by the hand in the angle formed between one of the guides *F* or *G* and the table, and the knife cuts off the projecting edge.

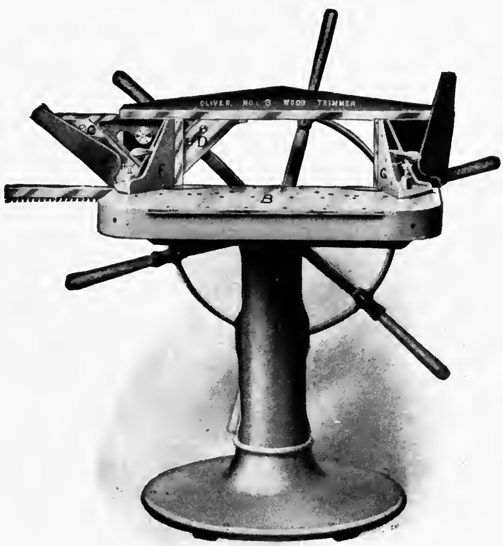


FIG. 106.—Wood Trimmer.

The large wheel at the back of the trimmer moves the knives back and forth along the table edge.

234. Materials used for Patterns.—The usual and best adapted material for patterns is wood, although a great many foundries which make large quantities of one article use patterns made of brass or other metals, to avoid excessive wear on them.

A suitable wood for patterns must have the following-named requisites:

(1) It must be well seasoned and must not warp.

(2) It must be straight grained and free from large or small knots which will interfere with ready working or prevent a smooth finish.

(3) It must not be subject to shrinkage with age.

The three woods much used for patterns are *white pine, mahogany,* and *cherry,* although other woods are more or less used in many localities. Red wood is much used on the Pacific coast. Mahogany is the best of these woods, but it is expensive and its use is therefore limited to small and medium-sized patterns requiring durability and permanence of shape.

Pine is much used for large patterns and for the ordinary run of small patterns.

235. Joints and Cuts in Woodworking.

Ripping is sawing wood along the grain.

Cross cutting is sawing across the grain.

A warped board is said to be *out of wind.* It may be planed straight in the planer if only moderately out of wind so that but little material needs to be removed.

In Fig. 107 the cuts commonly designated in woodworking are lettered as follows:

a, a. Chamfering or cornering.
b. Rabbeting.
c. Filleting (in contrast to square corner *d*).
f. Plowing.
g. Gaining.
h. Checking.
k. Raised paneling.

Specimens of wood joints are:

l. Mortise and tenon.
m. Tongue and grove, or matched joint.
n. Dovetail.
p. Miter joint.
r. Half joint.
s, t, u. Scarf joints.
w. Segment work.
x. Stave work.

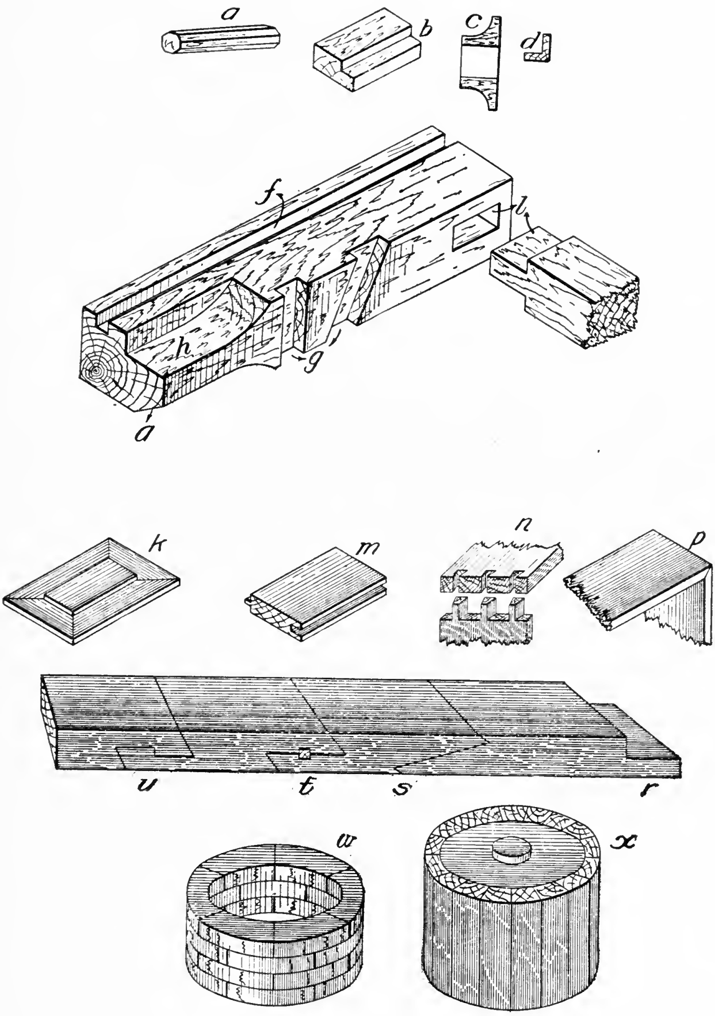


FIG. 107.—Cuts and Joints used in Woodworking.

236. Essential Features of Patterns.—A pattern must serve the purpose of making a mould which, when filled with molten metal, will produce a casting of a certain form and size. It would at first thought appear that to serve this purpose the pattern should be made an exact model of the desired casting. This is true only for some small simple patterns. There are some styles of patterns, or rather substitutes for patterns, which bear little if any resemblance to the moulds to be shaped from them.

The essential features which enter into the making of patterns and which are made necessary by considerations of their practical use are outlined in paragraphs 237 to 241 inclusive.

237. Shrinkage Allowance.—Metals contract more or less in cooling; hence when the molten metal which fills a mould begins to cool, it also begins to contract, and when cold the casting is smaller than the mould. To obtain a casting of the size designated on the drawing, its pattern must be made slightly larger than the casting. This enlargement in the size of a pattern is called the *shrinkage allowance.* The amount of this allowance varies with different metals and with different-sized castings of the same metals, hence the allowance necessary for each pattern is judged more or less by the experience of the pattern maker. The usual shrinkage allowances average about as follows, viz.:

Cast iron	1/8	inch	per	foot.
Heavy brass	1/8	"	"	"
Steel	3/16	"	"	"
Thin brass	3/16	"	"	"
Aluminum....................	7/32	"	"	"
Lead	7/32	"	"	"

In laying out a pattern from the drawing the pattern maker uses the *shrinkage rule* for measurements. This is a rule which has the shrinkage allowance added, as, for example, a two-foot shrinkage rule for cast iron would be 24¼ inches long, graduated in inches and fractions. Each standard inch and fraction is thus increased by an amount equal to the shrinkage allowance.

Castings which are to be machined to a definite size must not only have an allowance made for shrinkage, but a certain amount

of extra metal must be allowed for finishing. Also that part of the casting which is uppermost in the mould frequently has a still further allowance of metal to contain impurities and air bubbles which float to the top of the casting and may be imprisoned therein when the mould is poured.

The shrinkage allowance for small castings is sufficiently provided for by the rapping given a pattern to loosen it when it is removed from the sand of the mould.

238. Drawing a Pattern from the Mould.—After the sand is packed about the pattern in a mould, the pattern must be withdrawn before the mould can be filled with metal. In determining how a pattern shall be built, the first consideration is to decide how it shall rest in the mould with relation to the joints between the parts of the mould, so that it may be withdrawn without tearing the sand. It is usual to give a pattern a slight taper to facilitate its withdrawal.

This taper or "draft" is all that is necessary for the ready withdrawal of small and simple patterns, but the majority of patterns are of such shapes that they must be made in two or more parts, easily separable, to get them out of the mould. These parts are held together by dowel pins. A pattern is usually divided along its plane of symmetry into two parts, and is so moulded that this division coincides with the parting of the mould. A mould is also usually made in two parts, the upper of which is called the *cope* and the lower is called the *drag* or *nowell.* When the upper part of the mould is lifted away from the lower part, the upper part of the pattern is lifted with it. Each part of the pattern can then be lifted from the sand after a light rapping.

If either part of the pattern has any projection which would tear the sand in withdrawing, it must be dowelled in place in such a manner that it will be left behind when the part to which it is attached is withdrawn, or else the mould must be so built that a section of it may be taken away as a "drawback" before that part of the pattern is lifted out.

Figs. 108 and 109 show examples of simple patterns suitably made for withdrawing from the moulds.

Fig. 108 shows two views of a gland G to be cast hollow. The bolt holes b in the flange and the taper at the end d are cut in the machine shop after the casting is made. This gland is cast from the

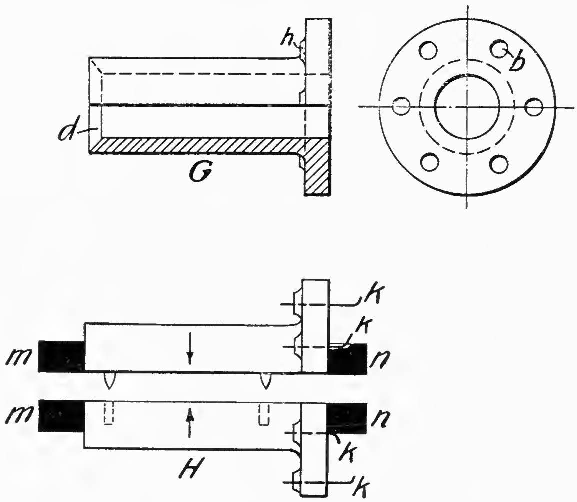


FIG. 108.—Metal Casting and its Pattern.

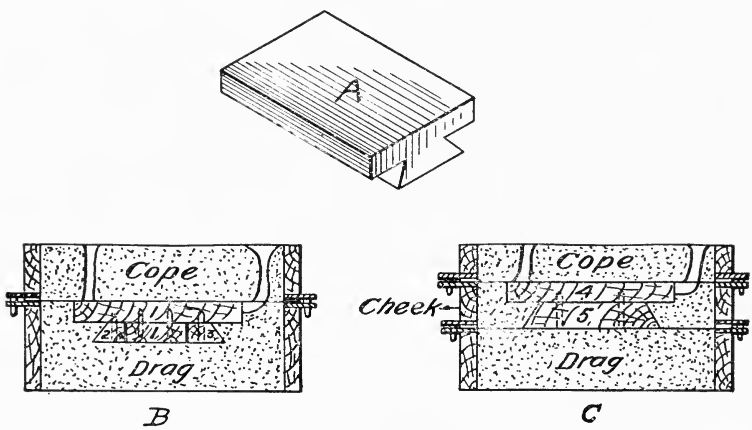


FIG. 109.—A Casting and its Patterns.

pattern H, placed horizontally in the mould. The halves of the pattern are separated in the view to show the line of parting. The bolt holes are reinforced by small raised pieces h. cast with the flange. If these projections were made fast on the pattern they

would tear the sand of the mould when each half of the pattern was lifted out in the directions of the arrows, hence they are held on the pattern flange by small wires *k* which are withdrawn when enough sand has been rammed against the flange to hold the projections in place. The pattern may then be withdrawn from the mould, leaving the projections behind, and these are drawn out horizontally into that part of the mould space which was occupied by the flange.

In Fig. 109 the moulds *B* and *C*, of the same casting *A*, show two methods of constructing a pattern for ready withdrawal from the sand. The mould *B* is the simpler. In this mould, the cope is

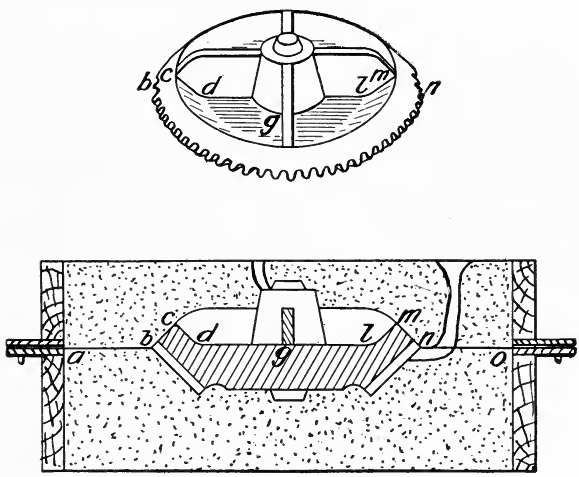


FIG. 110.—Pattern and Mould of Gear Wheel.

lifted, the parts marked 1 are lifted out together, and the parts marked 2 and 3 are then removed by first drawing them horizontally into the space left by the lower part of 1.

In the mould *C*, parts 4 and 5 are merely dowelled together. The cope is lifted, part 4 is lifted, and the cheek is then lifted, leaving part 5 on the parting between the cheek and the drag. In a mould of three parts, the middle part is called the cheek.

The pattern of the bevel wheel shown in Fig. 110 is made in two parts. The hub and the spokes are made as one part. The mould of the wheel is parted along the line *a b c d g l m n o*, so that the hub and spokes will lift with the cope.

239. Core Prints and Core Boxes.—A hollow, recess, or cavity in a casting is usually made by means of a baked-sand core. This core is placed in the mould after the pattern is removed. It occupies the space to be made hollow and is surrounded by metal when the mould is poured.

The pattern is not recessed nor made hollow to correspond with the casting, but, instead, is made as shown in Fig. 108, with solid projections or *core prints* extending from the part to be hollowed out. The prints in the figure are marked *m* and *n,* and when the two parts of the pattern are together, the end view of each print is, in this case, a circle. These prints have the same axis and are of the same diameter as the hollow part of the casting. The impressions which core prints make in the mould serve as bearings to support the ends of the core.

The pattern maker must supply with the pattern a *core box,* as in Fig. 111, in which the moulder shapes the core. A core box is

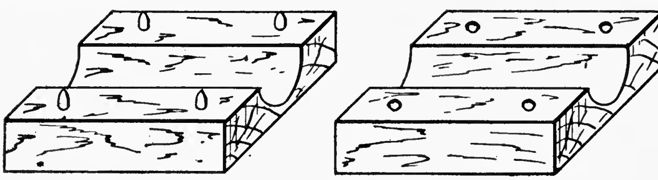


FIG. 111.—Core Box.

usually made in symmetrical halves for the purpose of removing a core readily after the sand composing it is properly rammed therein. The halves are placed correctly together by aid of wooden dowel pins and the moulder holds the box together with a clamp.

In many cases, cavities or hollows can be moulded without the aid of cores. Patterns are then made, without core prints, to the contour of the desired casting.

FIG. 112.—Square and Filleted Corners.

240. Fillets.—Sharp angles caused by the meeting of surfaces in different planes should be avoided in solid metal work wherever possible. A sudden change in the direction of a surface, causing a

sharp angle as at *B*, Fig. 112, is detrimental to the strength of a casting or forging in the angle. This condition may be avoided by making the change of direction gradual, as at *C*. In shop parlance, the corner *C* is said to be filleted.

Pattern shops are supplied with a soft metal fillet material wound on reels. This is tacked in all angles of patterns where fillets are not made in the wood itself in the course of shaping it for the pattern.

241. The Prevention of Warping.—Intricate patterns, whether small or large, must be made of several pieces of wood so joined together by glue that the tendencies of the several pieces to warp may be counteracted. This is accomplished by placing the pieces

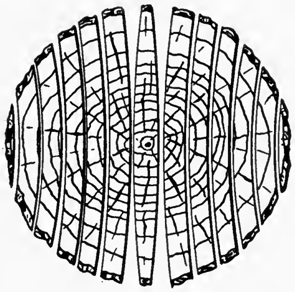


FIG. 113.—Tendency in Warping.

together so that the grain of adjacent pieces runs in different directions. A very common example of this is seen in the segment work of Fig. 107. Also, it may in some cases be advantageous to note the part of the log from which the wood is cut. The direction in which a board tends to warp is shown by the log end in Fig. 113.

242. Marking and Preserving Patterns.—It is very essential to shellac or varnish wood patterns to keep them from absorbing moisture from the sand of the mould. This smooth coating also assists in drawing them from the mould.

After applying shellac or varnish, many shops paint patterns red for cast-iron castings and brown for steel castings. Core prints and core boxes are almost always painted black. Occasionally some part of a pattern is made merely to enable the pattern to be drawn from the mould and is not to be reproduced in the casting. Such

a part is usually striped with black to designate to the moulder that the space it leaves in the mould is to be filled up with sand.

Patterns are too expensive to be thrown away when the castings desired are made from them. Each pattern should be marked or tagged with a number and its name, and should be stored in a store room where it can be readily found. A record book of patterns is kept to show, among other things, how many patterns are in a complete set for making, for example, the several castings of an engine.

243. Pattern-Shop Accessories and Methods.—Experience in pattern building has brought into use a number of helpful appliances and methods which greatly assist efficiency and rapidity of work, and which are mentioned specifically in this and the two paragraphs following.

The work bench is the center of the pattern maker's activities. This bench is particularly designed and equipped for his convenience in saving time. Essential fittings are (1) the bench vise, (2) the adjustable bench stop against which work is held for planing, (3) the bench hook for steadying work while sawing, chiseling, boring, etc., (4) the miter box to guide the saw in cross cutting a piece at angle of 30°, 45°, 60°, or 90° to its length, and (5) a rack at the back of the bench on which tools can be placed in a certain order for finding them readily.

244. The Laying-Down Board.—Adjacent to each bench is a large drawing board, about 6 x 8 feet in size, made of clear soft wood of sufficient thickness to be rigid, and conveniently supported.

When the pattern maker receives from the drawing room a working drawing from which a pattern is to be made, his first step, after determining the allowances for shrinkage and finishing, is to copy the drawing to full size on the board, marking with compasses and steel scriber, and using the shrinkage rule for measurements.

The next step is to decide how the pattern shall be drawn from the mould, and then the method of putting it together is decided, *i. e.,* the way in which the various pieces of wood composing it shall be joined. The pattern maker is now ready to get out the needed material and work it into shape.

245. The Marking-Off Table.—The building of patterns and finishing them accurately to shape is greatly assisted in many cases by a marking-off table. This is a flat cast-iron slab about 4 x 6 feet

surface which is ribbed underneath for rigidity. It is mounted as shown in Fig. 114. The sides and ends are at right angles to the top.

Such a table affords a level base for the purpose of accurate building up or measuring a pattern, particularly when its parts are intricate.

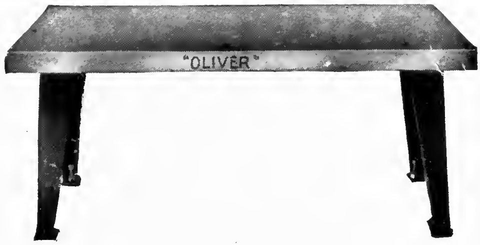


FIG. 114.—Marking-Off Table.

246. Varieties of Patterns.—In forms of construction, patterns may be divided into three varieties, viz., (1) solid patterns, (2) hollow and skeleton patterns, and (3) sweeps.

Small patterns are built solid, made up in most cases of parts so glued together as to prevent warping. Some large patterns are also made solid for rigidity. Hollow and skeleton patterns and sweeps are made to save expense.

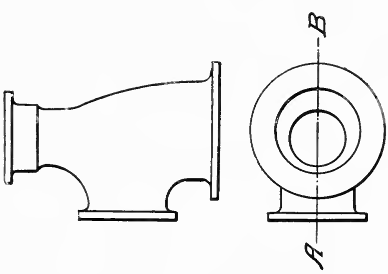


FIG. 115.—Steam Nozzle.

Large hollow patterns may be built up of segment work or stave work as shown in *W* and *X*, Fig. 107.

247. Skeleton Patterns.—The skeleton pattern is well adapted to irregular hollow castings, such as the steam nozzle with three outlets, a drawing of which is shown in Fig. 115. The pattern is made in two parts divided along the plane of symmetry *AB*. In building

this pattern, the three outlet flanges are built in halves of segment work, and these are joined by skeleton framing made up as a backbone, ribs and battens for each half. The marking-off table may be used to great advantage in this work.

Fig. 116 is a simple form of skeleton pattern shown merely to illustrate the method of building and using this kind of pattern. This is the pattern of a plain length of cylindrical pipe. Each half is formed of a backbone, two ribs, and four battens.

The lower half of the pattern is made so that the *inner* surfaces of the backbone and other parts are faired to the contour of the *inner* surface of the casting, and the upper half is made so that its

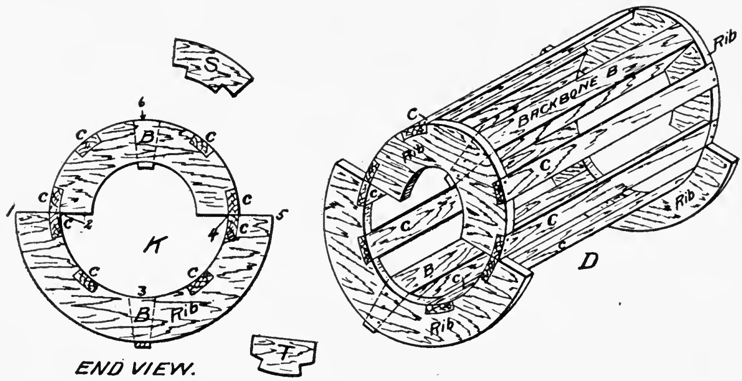


FIG. 116.

outer surfaces are faired to the contour of the *outer* surface of the casting. The battens C occupy part of the space of the walls of the casting.

In making a mould from this type of pattern, the moulder beds the lower half of the pattern in the sand of the lower half of the mould, making the parting along the line 1, 2, 3, 4, 5.

The core for the casting is then formed of sand and other materials in the space enclosed between the two halves of the pattern. The core is built up as far as can be done before placing the upper half of the pattern. When this half is placed, the core surface is carried to the outline of the semi-circle 6. Non-plastic pasting sand is sprinkled over this surface (as was done over the joints 1, 2, 3, 4, 5) and the upper half of the mould is built thereon.

When completed, the upper half of the mould is lifted off, and the sand is scraped from between the several battens and backbone joining the two end ribs of the upper half of the pattern by means of the small strike or strickle *S*, which scrapes away the sand to the thickness of the batterns *c*. The upper half of the pattern is then lifted away, exposing the true surface of the upper half of the core. The core is then lifted out, and the strike *T* is used to scrape away the sand between the longitudinal parts of the lower half of the pattern, after which this half is lifted out.

The strikes *S* and *T* have scraped out the sand which occupied the space for the casting. After the lower half of the pattern is lifted out, the mould is smoothed, the cavities left by the four end ribs are filled to the extent needed, and the core is replaced in the mould. The mould is now complete, ready for pouring.

248. Sweeps.—When the surface of a casting, such as a steam cylinder, a propeller blade and hub, etc., is wholly or in its main features a surface of revolution, or may be generated by the revolution of a line about a fixed axis, the mould for such a casting may be formed almost entirely by the use of sweeps in place of patterns. Such parts of the casting as are not surfaces of revolution are moulded from patterns used in conjunction with the sweeps.

Sweeps are made up of pieces of pine board cut to such a profile that they will form the surfaces desired when revolved on a vertical spindle which is the axis of revolution of the casting to be made. The generating edge of the sweep forms a surface in plastic sand on a facing of brick work gradually built up to the contour of this edge as the sweep is moved back and forth by the moulder.

Sweeps are used in making very large moulds built of bricks, known as loam moulds, and not for small moulds made of sand in boxes or flasks. Several sweeps are required to make a complete set. The use of sweeps will be shown in a description of making a loam mould in the next chapter.

CHAPTER IX.

THE FOUNDRY.

249. The Work of the Foundry.—The work of this shop is divided principally between moulding and casting. Moulds are prepared by aid of patterns sent from the pattern shop, and are filled with molten metal which solidifies to the more or less rough outline of the casting desired.

250. Iron, Brass and Steel Foundries.—The methods used in iron and brass foundries are closely associated, and these two branches are usually under one shop superintendent and in adjacent buildings. The steel foundry is separate, as its methods are enough different to be classed alone.

In location, it is highly important that a foundry site shall be well drained and without an excess of sub-surface moisture. Large moulds must be bedded in pits 8 or 10 feet deep to secure them for withstanding the great pressure of a large bulk of molten metal. If the soil over which the foundry is built is not a loose sand or loam, it must be dug out to a depth of several feet where large moulds are to be bedded and filled in with friable earth not pasty with an excess of clay.

251. Classes of Moulds.—There are four general classes of moulds, designated as follows:

(1) Open sand moulds.	(3) Dry sand moulds.
(2) Green sand moulds.	(4) Loam moulds.

Open sand moulds are the cheapest class of moulds. They are merely depressions made in a carefully leveled bed of sand in the foundry floor. The upper surface of the casting remains exposed to the air when poured. Only rough castings, flat on top, for foundry uses, are made in open sand moulds.

Green sand moulds are so called because they are moulds in damp sand, not baked or dried. They are the cheaper class of moulds, and are usually made in wooden flasks. With increased skill in moulding they are now extended to embrace moulds for large and

somewhat complicated castings, thus reducing the cost of production. The greater part of the castings of commercial objects are made in green sand.

Dry sand moulds are virtually green sand moulds carefully made, generally in iron flasks, and dried in a mould oven to make the sand firmer and more stable. This class of moulds is used for castings which have a complex form, and which must be smooth, sound, correct in shape, and free from internal strains. Superior castings are produced by this method, and the cost is about 1.5 times the cost of similar castings from green sand moulds. A dried mould surface can be given a very smooth finish, producing very smooth castings.

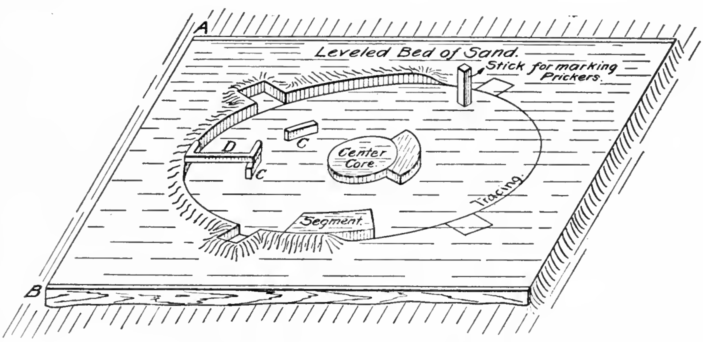


FIG. 117.—An Open Sand Mould.

Loam moulds are used for large complicated and important castings, such as large steam cylinders, propeller blades, etc. A loam mould is built of bricks on large, flat, rigid, cast-iron plates. The bricks of these moulds are faced with loam to form the mould surface.

Loam and dry sand castings are about the same in quality, and the relative expense of the two kinds of moulding depends upon the shape of the casting and the quantity to be made.

252. Example of an Open Sand Mould.—Fig. 117 shows an open sand mould in course of preparation. This is very simple and demands no particular skill. Two boards, *A* and *B*, are imbedded on edge in the foundry floor and are leveled along their length and across from one to the other. The sand between them is tamped

down and leveled off by a straight-edged board drawn along A and B, and a tracing of the plate to be cast is marked on this bed of leveled sand. The outer edge and the center core of the mould are formed by pressing damp moulding sand with the hand firmly against wooden segments made to the necessary curvature. The center core will core a hole in the center of the plate, and smaller holes may be cored anywhere desired in the plate by small baked cores C, C, which are kept from floating or washing out of position by convenient weights, as at D. Lifting-lugs are provided at the edges of the plate. This is a type of plate frequently used to form the top of a loam mould. Small projections or prickers are usually

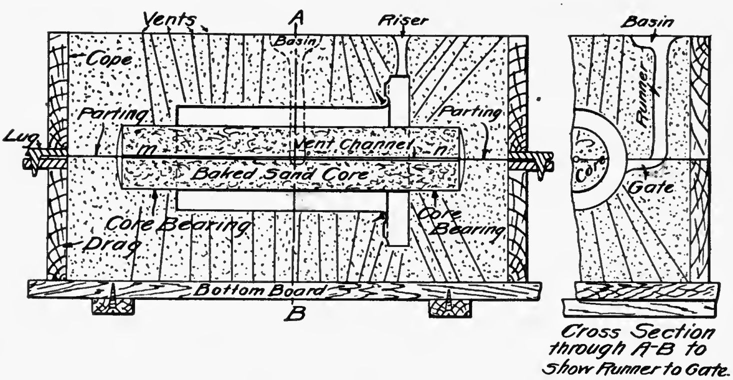


FIG. 118.—Example of a Small Green Sand Mould.

cast on the under side of the plate to assist in holding the loam coating which the plate must carry as a part of a loam mould surface. Impressions are made for these prickers by sticking holes in the sand with a small stick, or the prickers may be formed by sticking two-inch nails in the bottom of the mould so that metal poured in the mould will solidify about the nail heads.

253. Example of a Green Sand Mould.—Fig. 118 shows a typical small green sand mould in a two-part flask. This is a mould of the pattern shown in Fig. 108. The upper half of the mould is the *cope* and the lower half is the *drag* or *nowell.* The two parts of the mould are separated at the *parting.* The casting is made hollow by the *core,* resting in its bearings. A number of *vents* are punched by a small steel wire before the pattern is removed. The vents con-

duct away gas and steam generated in the sand by hot metal, and prevent the escape of these into the mould. Before pouring, the mould is weighted down to keep the cope from floating. Metal is poured from a ladle into the *basin,* entering the mould through the *runner* and *gate.* Many moulders designate the runner as the *sprue.* As pouring continues, metal gradually fills the mould and rises to the top of the *riser.* Vent gases escape at the top, around the parting and along the bottom board. Air escapes from the mould cavity through the riser as metal is poured in. A small vent channel runs through the core, conducting gases to the parting. A single flask often contains several moulds of small castings, all run from the same sprue.

254. Essential Features of a Mould.—All moulds, whether for steel, iron or brass, must fulfill the following general requirements, viz.:

(1) They must be made so that the pattern can be removed readily therefrom.

(2) Not only must an opening be made in the sand for pouring metal into the mould, but a riser hole must lead upward through the sand from each of the high parts of the mould cavity. This serves (a) to keep air from being imprisoned in the mould when metal is poured in; (b) to allow for loose sand and scum on the metal to float out, and (c) to provide a bulk of hot metal to "feed" the casting as it shrinks in solidifying.

(3) A mould must resist burning and crumbling when filled with molten metal, and must resist bursting from the static pressure of the metal.

The requisite qualities of sand for moulds will be mentioned later.

255. Foundry Equipment.—The main equipment of the foundry may be stated as follows:

(1) Moulding sands in bins, and other moulding materials.

(2) Flasks in which moulds are made.

(3) Moulders' tools and accessories used in making moulds.

(4) One or more traveling cranes equipped with various lifting and transporting appliances.

(5) Usually two or more cupolas for melting pig and scrap cast iron.

FIG. 119.—A Moulding Floor.

(6) A reverberatory oil or coal furnace for melting bronze or brass for large castings.

(7) A crucible furnace for melting brass.

(8) Ladles for holding molten metals.

(9) A drying room or "oven" for drying dry sand and loam moulds.

(10) A core oven for drying or "baking" cores.

(11) Equipment for cleaning castings, as wire brushes, emery wheel, and tools for cutting fins and other refuse parts from castings, tumbling barrels, etc.

Moulding machines are used to make small moulds in foundries which turn out duplicate work. There are several subsidiary machines for foundry use, such as sand mixers, clay grinders, etc., but these are not universally needed. Fig. 119 shows a view of a moulding floor of a foundry.

256. Moulding Sand.—This is the most important of the moulding materials. In different forms, it has different uses and is given different names, such as *green sand, loam, facing sand, core sand, brass sand.* All moulding sands are essentially mixtures of silica to give porosity and clay to give tenacity. Silica grains are refractory and have no cohesion. Clay is a fine powder, is refractory and when wet is adhesive and plastic. These two ingredients are mixed in different proportions, the silica grains varying in size, to make mixtures suitable for different uses.

Other materials are mixed with moulding sands for various purposes, as will be mentioned.

All moulding sand mixtures are more or less wet when formed into moulds. The requirements of a good moulding sand are:

(a) Sufficient *porosity* to allow the escape of gas and steam generated in the body of the mould by the heat of the molten metal. The greater the bulk of metal the coarser the sand used, and the greater the need for careful venting.

(b) Sufficient *plasticity* and *tenacity* to hold its form in the mould and to resist the erosive action of hot metal. These qualities are due to clay, which is more or less detrimental, because it fills the spaces, or pores, between the silica grains.

(c) A high enough *fusing point* not to melt and stick to the face of the casting.

There are many trade names for foundry sands, but all must fulfill the requirements mentioned. Vegetable or other combustible matter, sea salt, lime, and substances easily decomposed by heat should not exist naturally in moulding sand, as they may cause failure in casting.

Brass sand is green sand of fine grain used in moulds for brass castings.

Facing sand is also a fine-grained sand placed next to the pattern in small moulds to make a smooth casting.

Core sand is used for cores.

Loam is a very course moulding sand made up for loam moulds.

257. Other Materials Used in Moulding.—Designating moulding sand as first on the list, other important moulding materials are named as follows:

(2) *Fire clay* is a pure clay (oxide of aluminum) much used when mixed with water as a plastic refractory material for patching ladle and cupola linings, and for use in moulding.

(3) *Clay wash* or *clay water* is a thin mixture of fire clay and water. It is added to moulding sand mixtures (particularly loam mixtures) to give them the necessary plasticity. It is also used to wet sticks, nails, iron rods, core irons, etc., imbedded in moulds and cores to make sand adhere to them, thus strengthening the body of the mould.

(4) *Common red bricks* are used to make the body of loam moulds and to fill up remote spaces in large dry sand moulds. They are piled evenly in the spaces they occupy, and afford porosity.

(5) *Parting sand* is sprinkled on the joints or partings of moulds, as between the cope and the drag, to keep the two parts of the mould from sticking at the joint. Any fine-grained non-plastic material, such a brick dust, silica sand, ground cinders, etc., may be used.

(6) *Slurry* is clay wash and fine moulding sand mixed thick. It is used as the first smooth coating over the rough loam surface of a loam mould.

(7) *Cinders* from completely burned coal are used in venting to assist the porosity of large cores and sand projections in moulds, and are placed under large moulds to receive and convey gases from the moulds.

(8) *Blacking and sleeking mixtures* are used as a final smooth coating over the surface of a mould after the pattern is withdrawn. These are known as mould facings, facing mixtures, etc. They give a smooth surface to the casting. Some mixtures contain molasses, stale beer, or other viscous substances, to prevent the sand of the mould washing away when metal is poured. Facings of *powdered slaty coal, charcoal, graphite, soapstone,* or *ground silica,* are dusted on the faces of green sand moulds from small muslin bags. These are applied wet, with a brush, to dry sand and dried loam moulds, and are slicked when nearly dry to make a smooth glossy surface.

(9) *Flour, stale beer, oil,* and *molasses* are used to increase the tenacity of sand in moulds. A more important feature of flour is that it chars when metal is poured into the mould, allowing core sand to disintegrate and crush as the casting contracts in cooling. *Flour paste* and *putty* are used to make a tight joint between a core and its bearing.

(10) *Oil* is used to coat large patterns in loam moulding to keep the loam from sticking to the pattern.

(11) *Loose or chopped straw* and *dry horse manure* are used in loam moulds to increase porosity, and *straw rope* is wound on "core barrels," or large metal pipes, which are then covered with loam and dried for use as cores for moulding large water and gas-main piping.

The moulder applies the name of *sharp sand* or *fire sand* to silica or any other kind of gritty, non-adhesive sand. *Burnt sand* is a sand which has lost its tenacity by having been highly heated next to a casting in the mould. Burnt sand must have new sand mixed with it to fit it for moulding, though the worst of it is thrown away.

Loose sand and refuse must not be allowed to accumulate about the foundry floor.

It will be seen that many of these materials are to assist one or more of the three essentials, *a, b, c,* mentioned in the preceding paragraph, for moulding sands.

258. Flasks for Green and Dry Sand Moulds.—Moulds of these two classes are made in flasks of various shapes and sizes. Wood or iron flasks are used for green sand molds and cast-iron flasks are used for dry sand and steel moulds.

Fig. 120 shows three flasks extensively used for small moulds. Each of these consists of three parts—cope, drag and bottom board. Suitable lugs and pins are provided to insure the cope and the drag going together always in the same relative position. No. 2 may be poured from the top, or may be set on end and poured through one of the holes in the end to insure a better metal pressure in the mould. No. 1 is a snap flask, which may be removed from a mould and used for making other moulds of the same size. When this flask is removed, a rectangular box is slipped over the mould in its place to support the sand. No. 3 is for general use for small moulds. Each size of small flasks for general use should be made interchangeable, *i. e.*, the upper part of any flask should fit the lower part of any other flask.

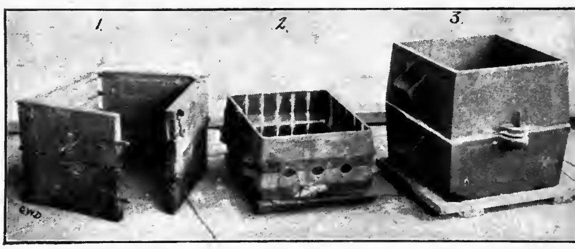


FIG. 120.—Small Moulding Flasks.

Fig. 121 shows two flasks for medium-sized moulds. The weight of sand in the cope is too great to hold in place without the *cope bars B*. The drag needs no bars, but it must have a bottom board if it is to be turned over in the course of making the mould.

The upper view shows a three-part flask for a pattern which cannot be removed from a single parting in the two-part flask. The cheek, or middle part of the flask, also has bars. These extend radially from corners and sides of the cheek toward the pattern, but bars should not be within less than about ¾ inch of the pattern surface.

Many cast-iron flasks are shown in the view in Fig. 119. They are made up of flat cast-iron sections bolted together, or of round sections made in one piece. A large cope is shown at *C* with rods and bars arranged for a particular casting. A circular cope and drag clamped together are marked *B* and *D*. Each of these parts

has a pair of trunnions by which it may be suspended and revolved while giving the mould its finishing touches.

Several minor devices are used for assisting cope bars to hold a body of sand firmly in place. Nails are frequently driven along the under edge of a bar to hold projections of sand in an irregularly shaped parting. Bent iron rods, called *gaggers,* are imbedded in the

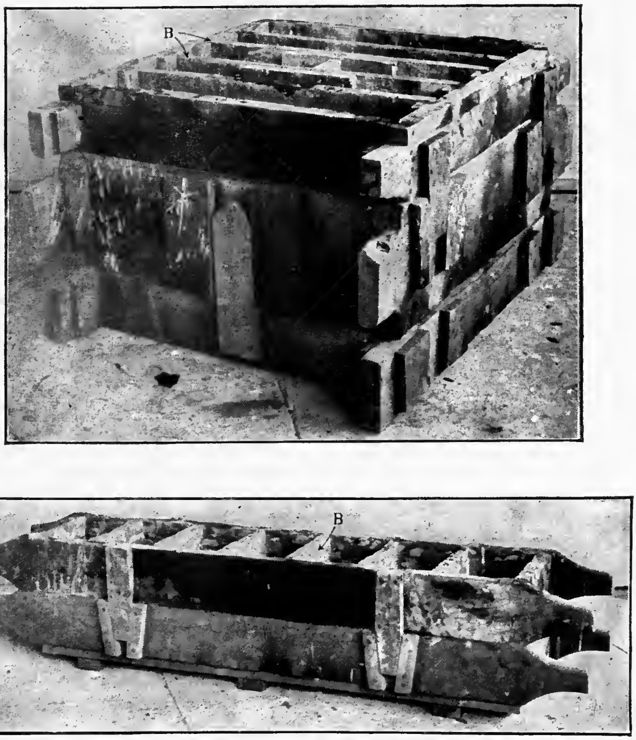


FIG. 121.—Moulding Flasks.

sand to anchor the unstable parts to the firmer bodies of sand in a cope or a cheek. Small tapered sticks, called *soldiers,* are used when the mould is delicate and cannot stand the weight of gaggers.

Loose nails are often imbedded in corners of sand or are stuck in the surface of a mould to hold the sand firmly against breaking or wearing away by erosion. Gaggers, nails, etc., are wet with clay water to make the sand stick to them.

16

259. Tools Used in Moulding.—The moulder's tool kit is simple and includes articles of the following list, most of which are shown in Fig. 122:

(1) Vent wire for sticking vent holes through the sand of the mould.

(2) Pattern lifter.

(3) Joint trowel and (4) heart trowel for smoothing and finishing the parting and flat surfaces of the mould.

(5) Gate cutter and pattern lifter.

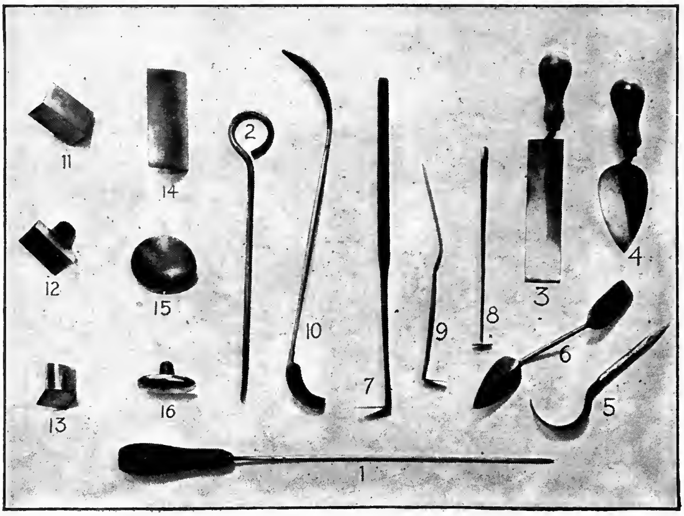


FIG. 122.—Moulding Tools.

(6) Slick and oval spoon for finishing mould surfaces.
(7) (8) Sand lifters and slicks.
(9) Yankee heel lifter and flat slick.
(10) Flange and bead slick.
(11) Corner slick.
(12) Edge slick.
(13) Round corner slick.
(14) Pipe slick.
(15) Button slick.
(16) Oval Slick.
(17) Hand rammer for ramming sand in flasks (not shown).

(18) Spirit level for leveling open sand moulds (not shown).

The slickers are used for finishing the surface of the mould after it has been dusted or painted with mould facing.

Additional equipment, usually a part of the foundry outfit, includes:

(1) Small bellows for blowing loose sand from moulds.

(2) Sieves (riddles) for sifting sand.

(3) Brushes for applying liquid mould facing and for dusting moulds.

(4) Small bags for dusting dry mould facing.

(5) Heavy and pneumatic rammers for ramming sand in flasks.

(6) Larger hand tools, as spades, picks, hoe, rake, hand spikes, crow bars, wrenches, buckets and sprinklers.

260. Example of Making a Small Mould.—The work of making a mould of the pattern in Fig. 108 is here given briefly to show the

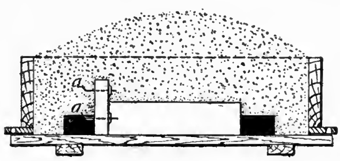


FIG. 123.

essential steps in sequence. This is applicable in general to green sand and dry sand work. The completed mould is shown in Fig. 118.

Having selected a suitable flask, place one-half of the pattern on the bottom board, as shown in Fig. 123. Place the drag bottom side up on the board, and sift about a half inch of facing sand over the surface of the pattern, then fill the drag heaping full from the pile of moulding sand, sifting part of it in. Ram this sand down firmly, but not too hard, and level it off even with the top edge of the flask by rubbing the sand surface with another bottom board, then lift the board and use the vent wire to probe several vent holes which will reach all parts of the pattern's surface. Dig down with the small trowel carefully until the wires *aa* can be reached and drawn out. Replace this sand and probe a few vent holes through it. Replacing the upper bottom board, turn the drag over and remove the other board, which is now on top.

The drag now rests right side up, as shown in Fig. 124. Place the cope and the other half of the pattern in position, as shown, and stick a riser stick *R* slightly into the sand, about 2 inches from the pattern. Sprinkle a layer of parting sand over the parting to keep the sand of the cope and that of the drag from sticking together. The cope is now filled, rammed, and otherwise prepared, as was described for the drag. The riser stick *S* is placed on the upper edge of the flange when there is enough sand in the cope to hold it up, and both sticks are withdrawn after the cope is vented.

When the cope is rammed and vented, lift it from the drag and remove the pattern by using the lifting screw. Rap it a few times to loosen the pattern before lifting. A little water squeezed from a swab around the edges of the pattern will help hold the sand in

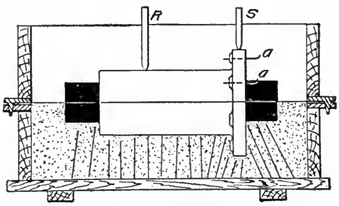


FIG. 124.

place. Patch the broken corners of the mould, cut the gate with a piece of bent tin, lift out any loose sand, and dust the mould surface with graphite or other dry facing.

In the meantime the core-maker makes the core. The core box, shown in Fig. 111, is clamped and gradually rammed full of core sand. Two wires are rammed in with the sand along the axis of the core. One of these remains in the core to strengthen it, and the other is removed when the core is rammed up to leave a vent hole.

The core must be carefully removed from the box. It rests on some loose sand placed on an iron plate, and is slowly baked in the core oven. Cores are usually sprinkled with molasses water to make them more flinty when baked.

When the core is taken from the oven and cleaned, it is placed in its bearings in the drag, and the mould is closed and weighted ready for pouring.

261. Moulding Machines.—These machines are profitably employed in foundries which make a great number of small duplicate castings. They are designed and built to repeat certain motions and operations which occur in the work of moulding all small castings. Each machine is operated by a workman who directs the machine and who performs those steps in the work which the machine cannot perform.

There are two types of moulding machines, known as the *vibrator* and the *squeezer*.

Snap flasks of special design and uniform sizes are used with these machines.

Moulding machines do not require skilled labor to operate them, and many small patterns may be moulded in a single flask.

262. Cores.—Cores are more or less surrounded by molten metal and are therefore subjected to more concentrated heat than other parts of the mould. To serve their purposes they must be made especially (1) to resist erosion from flowing metal, (2) to resist fusing, and (3) to allow the escape of air, steam and carbon gases contained in the core.

Clean silica sand of more or less coarse grain is the principal material of cores. About 15% of flour is mixed with this and the mass is wet with thick clay wash until the sand grains stick together.

All cores must be carefully vented to assist the natural porosity of the sand. Vent holes are usually formed by straight wires. Crooked vent holes are formed by greased strings. Vent wires and strings are pulled out before the core is taken from the core box. Large cylindrical cores may be made in halves for better venting, and all large cores contain cinders at the center to increase porosity. All vents must lead to the core bearings from which gases escape along the mould parting or through especially provided pipes or channels.

Small cores are strengthened by wires. Specially made core irons are enclosed in large cores to make them rigid enough for handling, and to support them in the mould.

The baking of cores makes the sand much firmer, and decreases the gases and moisture in them. Baking is usually necessary, but there are many shapes of cores which can be made of green sand as

a part of the mould. These are well vented and are well enough supported to avoid the necessity of baking.

Large cores for loam moulds are built of bricks and surfaced with loam and slurry.

For smoothness of surface, cores are blacked and slicked. This is done after drying.

263. Chaplets.—There are many cases in moulding in which a core is not adequately supported by its bearings in the sand of the mould, particularly if it has but one bearing or is not a straight core.

It is the practice in these cases to support the core by pieces of metal called chaplets, placed in the mould space. When metal is poured into the mould around the chaplets, they soften and become a part of the casting.

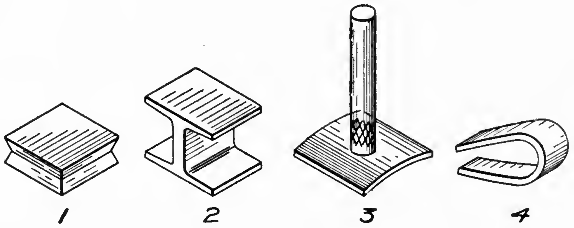


FIG. 125.—Chaplets.

Fig. 125 shows four of the many shapes of chaplets much used. These are of iron or brass as may be needed. Chaplets must be cleaned before placing them in a mould. They are often tinned.

It is frequently necessary to place a chaplet above a core to keep the metal from floating the core out of position, beside placing a chaplet under the core to support it before the metal is poured in.

There will be noticed often on the outer surfaces of hollow-cast pipe elbows, cone-shaped projections or rough spots which mark the position of chaplets.

Chaplets are sometimes used in narrow mould spaces to insure the required thickness of metal in the casting.

264. Chill Moulds.—Surfaces of cast-iron castings subjected to constant wear, such as car-wheel rims, anvil faces, and vehicle wheel boxes, are chilled to render them hard and tough. The chilling is done by sudden cooling of the molten iron when it is poured

into the mould. A part of the mould is formed of a piece of iron, and when the molten metal comes in contact with this, its surface is quickly cooled.

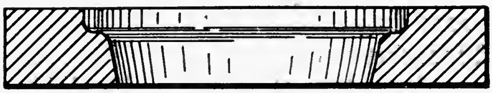


FIG. 126.—Chill for a Mould.

Fig. 126 shows a chill for a car wheel. This forms the cheek of a three-part flask. Chills are made of cast iron or cast steel.

265. Example of a Loam Mould.—Fig. 127 shows a cross-section of a loam mould, with the parts assembled and bound together

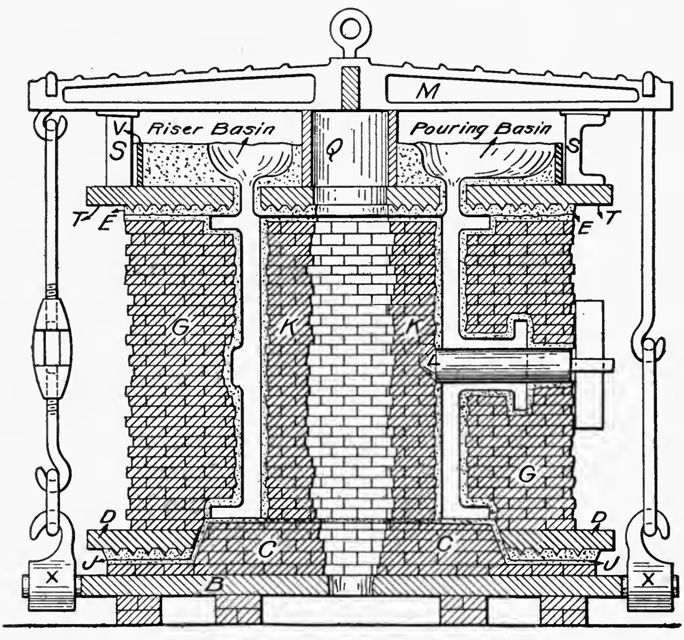


FIG. 127.—Loam Mould.

firmly. It is now ready to be lowered into a pit dug in the foundry floor and surrounded by sand packed inside a circular curbing of iron plates to fortify the sides against the pressure of the molten

metal when poured. Fig. 128 shows a drawing of the cylinder for which this mould is made.

Loam moulds are used only for the largest castings, particularly large propellers and steam cylinders. The bricks of these moulds may be used many times.

The mould here shown is made in three detachable parts carried on the heavy cast-iron plates *B*, *D* and *T*. The bricks are laid in a mortar of old moulding sand and water. Venting is aided by placing cinders between bricks, and by mixing chopped straw or dry horse manure with the loam.

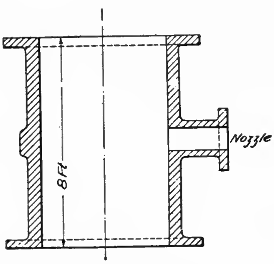


FIG. 128.—Cylinder to be Moulded.

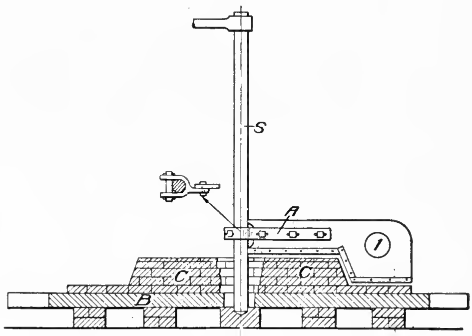


FIG. 129.—Beginning a Loam Mould.

266. Building a Loam Mould.—Each of the detachable parts of a loam mould is so built on its own plate that it can be handled separately from the other parts.

The mould is begun by leveling the heavy foundation plate B (Fig. 129) on firm supports, and supporting the spindle *S* vertically in its bearings in which it is free to turn. Sweep No. 1, with edges iron bound to prevent wear from the rough loam, is then bolted to the strap *A*. The foundation brickwork *C* is built up with this sweep as a guide, and about half an inch of loam is swept evenly over the top of the brickwork by revolving the sweep about the spindle. This loam facing, shown in Fig. 130, is allowed to dry and the joint *JJ* is well oiled.

The next part of the mould, the main body (marked *GG* in Figs. 127 and 131), is swept up on the lifting ring *D* by using sweeps 2

and 3. The steps of this work are shown in Figs. 130 and 131. The lifting ring is bedded in a layer of wet loam spread over the joint *JJ*. This loam sticks to the ring when dry and is lifted with it. Sweep No. 2 merely sweeps the temporary brickwork *FF*, which is

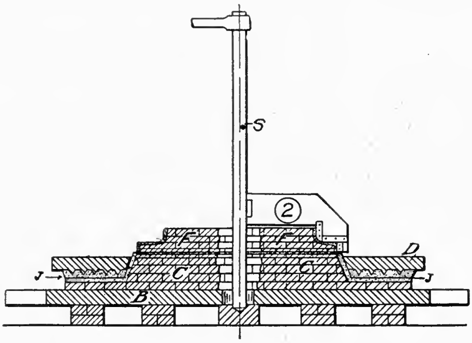


FIG. 130.—Sweeping up Dummy Flange.

loam coated to serve as a pattern against which the lower part of the main body is built. The revolving of the sweeps as the bricks are placed serves as a guide in placing them, and after the brick-work is done, the loam coating is plastered on by hand and swept

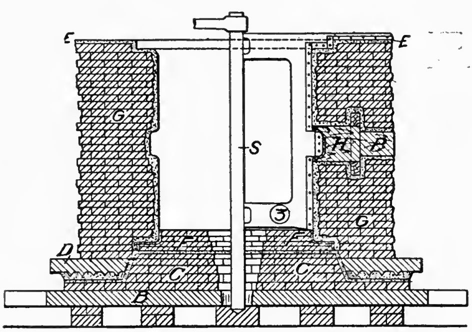


FIG. 131.—Sweeping up Main Wall.

to shape on the brick surface to form the surface of the mould, which is later made very smooth.

Any part of the casting, as the nozzle of the cylinder in Fig. 128, which projects beyond the surface of revolution, is moulded by bedding suitable wooden patterns of these parts in the brickwork. The pattern *H*, with its core print *P* (Fig. 131) and its detachable

flange, is surrounded by a loam coating as it is built in the wall of the mould. These patterns are removed after the mould is lifted apart.

When sweep No. 3 has completed its work, as shown in Fig. 131, the main part is lifted away on its lifting ring *D*, the temporary work *FF* is torn away, and the main core *K*, for making the cylinder hollow, is swept up as shown in Fig. 132. *L* is a small core print for the nozzle core, and *R* is a flat bar of cast iron imbedded in the core. The bar is removed just after the cylinder is cast, by digging down to its end and attaching the crane thereto. This re-

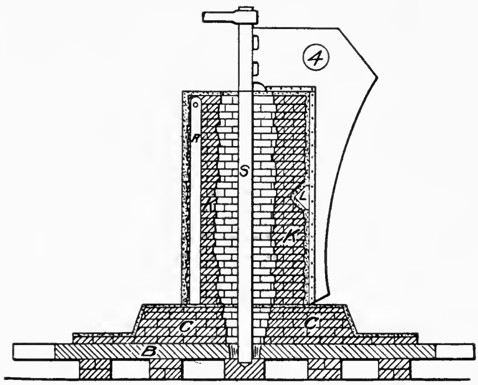


FIG. 132.—Sweeping up Main Core.

moval allows the casting to crush the core sufficiently in contracting to avoid cracking.

The assembled mould in Fig. 127 shows the top plate *TT* placed over the oiled joint *EE*. Loam has been swept on the under side of this plate and after the parts of the mould are assembled and bound, the riser and pouring basins are shaped of green sand held in place by the sheet-iron ring *V* and the heavy tube *Q*. The four-armed cross *M*, resting on distance pieces *Q* and *SS*, is bound to the foundation plate *B* as shown.

The parts of the mould are dried after they are swept up and lifted apart. This is done in a large brick oven and requires about 60 hours. Before finally assembling, the mould surfaces are painted with a liquid mould facing and carefully slicked by hand slickers.

267. The Cupola.—Pig and scrap iron for castings are generally melted in a cupola, although a reverberatory furnace may be used. Fig. 133 shows a typical cupola in cross-section. A cast-iron or cast-steel base ring *B* is supported about 3 feet from the ground by four iron posts *C*. This ring carries a shell *D* of steel plates lined inside with refractory bricks. The top of the cupola acts as a chimney, although the two or more cupolas necessary in a foundry may lead into a common chimney.

Under the base ring are hinged two iron doors, *FF*, held up by an iron prop when the cupola is in use. About 12 inches above the sand bed is the slag hole, and about 8 inches further up are the tuyere holes. The tuyeres are merely pieces of iron pipe extending through the cupola shell and brick lining. The tuyere holes are encircled by the blast or wind box which receives ordinary air at a low pressure from a blower and delivers it through the tuyeres when the cupola is in operation. The blast box has a small mica peep door opposite each tuyere to enable the melter to see the surface of the molten iron. The cupola is charged from the charging platform through the charging door about 9 feet above the bottom. The lining bricks are supported at intervals by angle iron lining-shelves as shown.

Cast iron melts at about 2200° F. If the cupola blower breaks down, a jet of steam in the base of the cupola chimney will induce a draft sufficient at least for slow melting.

268. Operation of the Cupola.—A cycle of service for a cupola in active use is usually repeated each 24 hours. Briefly the operation throughout the 24 hours is as follows: A day's melting having been finished, and the blower stopped, all metal and slag are drained out at the tapping hole. The prop is knocked away, and the doors *FF* swing down. The sand bottom and any unburnt fuel drop out.

Next morning the cupola is cool and the melter and his helper proceed to prepare it for use. Slag is chipped from the lining, which is patched where needed with plastic fire clay. Old sand is dug from the doors, breast and tapping spout. The doors are then propped up and the melter goes down through the charging door to prepare a new bottom. This is made about 4 inches thick, and con-

sists of a thin layer of cinder, a layer of new moulding sand and a coating of thick clay wash. The sand bottom continues out to the end of the tapping spout.

After the bottom has dried about an hour, a wood fire is built in the cupola. The breast is rammed with new sand around an iron pipe, and the pipe is then withdrawn to form the tapping hole.

Coke and iron are weighed out for the charge and are hoisted to the charging platform. A hot coke fire is gradually built up, the blower is started, and the charging begins. The charge consists of alternate layers of coke and iron, and each layer must be weighed to make the operation of the cupola uniform and to insure enough coke to melt the iron. Pig and scrap iron are charged together. Molten metal appears at the tapping hole about half an hour after iron is charged, and this hole is stopped with a clay plug jammed into place on the end of a heavy round stick.

In the meantime, the foundrymen are assembling the ladles to be used in pouring the moulds. A wood fire is built in each ladle to keep it from chilling the molten metal it receives. When enough molten metal accumulates in the cupola, the clay plug is dug out with an iron bar, ladles are filled, and the tapping hole is again stopped.

Charging continues from the upper platform so long as metal is needed, and when all moulds are poured, the remaining iron is run from the cupola and the blower is stopped.

269. Ladles.—Iron is received in ladles from the cupola and is poured from these into moulds. Ladles are made of rolled steel plate and plastered inside with a wet mixture of silica sand and fire clay. Large ladles are lined with fire-clay bricks, plastered over with clay. Small ladles are carried in *ladle shanks* by one or more men, and large ladles must be carried by the crane. A "bull shank" is shown in Fig. 31. Before receiving molten metal, ladles must be thoroughly dry.

Metal for a very large casting must be gradually assembled in several large ladles until there is enough to fill the mould. After it is tapped very hot into the ladles, it is kept hot by a charcoal fire on the surface of the metal.

All ladles and crucibles must be skimmed at the pouring spout

with an iron bar while pouring. Very hot metal makes a good impression in the mould, but is very searching, requires more venting of the mould, and shrinks more than a metal not so hot.

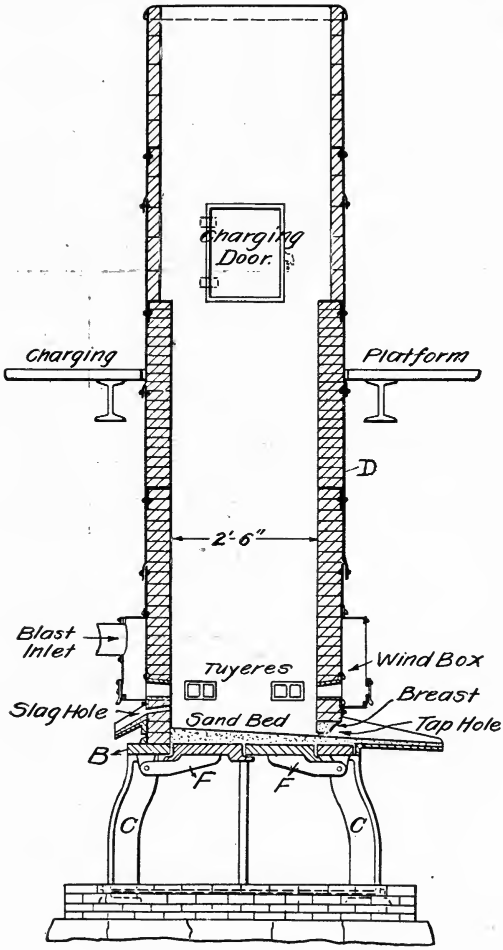


FIG. 133.—Foundry Cupola.

270. Foundry Iron.—Although foundry iron is now selected by its composition as shown by chemical analysis, yet the designations of *white, mottled,* and *grey* irons, are still used to classify pig iron according to the carbon it contains. White iron, with no uncom-

bined carbon, is too hard for castings which must be machined. Grey iron, with much uncombined carbon, is easiest to melt and easiest to cut. A mottled iron is strong, tough and not difficult to machine.

Cast iron containing much free carbon expands upon cooling, due to separating out of graphite from solution. This is an advantage in casting, as it balances the contraction due to cooling.

Scrap iron must not be used in high-grade castings unless it comes from similar castings.

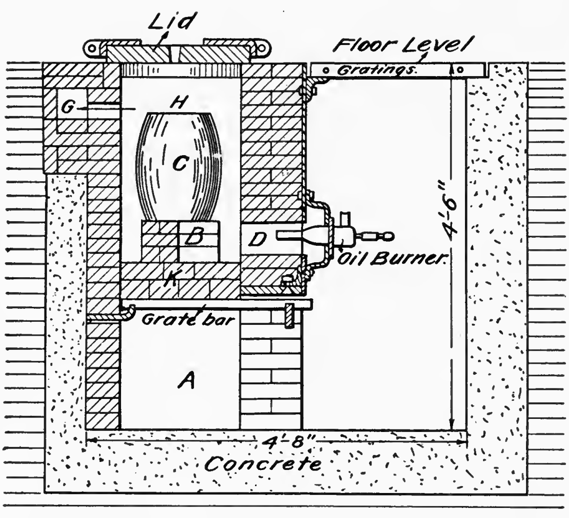


FIG. 134.—Brass Melting Furnace.

271. Brass Furnaces.—The materials and methods used in making iron and brass moulds are practically the same, although the means of melting these metals for castings are different because brass melts at a lower temperature (brass about 1700° F., copper about 2000° F.) than does iron.

Fig. 134 shows a typical crucible furnace for melting brass. It is shown as arranged for oil fuel, but may be used for hard coal or coke by removing the oil burner, stopping up the burner hole *D* and removing the bricks *K* from the grate bars.

There are patented forms of oil furnaces which are self-contained and may be set at any place desired about the foundry floor.

A reverberatory furnace is used to melt brass for a large casting, but if this is not installed, a large casting can be made by assembling in a large ladle the molten metal from several crucibles.

In Fig. 134, the furnace is built of brick in a concrete-lined pit. The melting space *H* is enclosed by fire-brick walls and covered by a movable lid. A furnace is composed of a number of these melting spaces in a row.

The burner forces oil and air through the opening *D* into a flame which strikes the corner of the base *B* and surrounds the crucible *C*. The chimney conduit *G* conducts gases of combustion to a tall chimney.

Two bricks on edge, or better, a bed of glowing hard coal must hold the crucible off the grate bars when coal or coke heating is done, otherwise its bottom would be too much cooled from the air through the bars to allow melting of the contents. The ash pit *A* is large enough to afford a good draft for coke or coal.

Brass is alloyed by melting the required amount of copper and then stirring in the zinc in small pieces with an iron rod. Salt, sal ammoniac, or charcoal may be used as a flux to avoid oxidation of the surface of the molten metal. Scrap brass must not be used in high-grade castings unless its composition is known to be the same as that intended for the castings. Even then, a careful fluxing is required to remove any possible oxidized metal contained in the scrap.

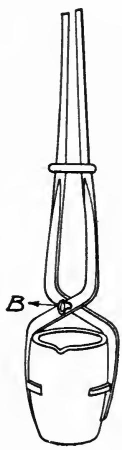


FIG. 135. Crucible Tongs.

Fig. 135 shows a pair of tongs for lifting crucibles from brass or crucible-steel furnaces. A tackle hooked to the eyebolt *B* lifts the crucible and lowers it into a ladle shank. The mould is poured from the crucible.

272. Defects in Castings.—The following defects and their causes are well known to foundry men:

(1) *Surface and interior cavities* are caused by too little metal, or by runners and risers too small to remain liquid and feed the casting until it has "set" throughout its mass.

(2) *Cold shuts* are caused by chilled metal. When poured, sluggish metal becomes so chilled that it does not unite when it meets from opposite sides of the mould.

(3) *Blow holes* are caused by air, gas, or steam under the surface of the casting when it solidifies. Blow holes are from air entrained in a partially filled runner, from air entrapped in the mould space and from steam forced into the mould from the sand due to improper venting and drying. If a metal is very fluid when poured, air and gases will rise to the surface and escape. The metal itself contains little or no gas before pouring.

(4) *Sand holes* and *cuts* are formed by loose sand in the mould. Sand from the mould surfaces may come off in patches known as "scabs" due to poor venting. If the patch of sand breaks up, it forms *sand holes,* but if it remains intact, metal encloses it and forms a *cut.* Sand will float if the metal is sufficiently fluid.

(5) *Shrinkage cracks* are caused by a mould or core too rigid to allow a casting to shrink without cracking.

(6) *Strains* and *warps* are caused by uneven cooling. A strain is not visible, but may cause the casting to crack if hammered. A warp distorts the shape of the casting.

(7) *Sponginess* is caused by impurities in the metal when poured. It generally shows in brass or bronze castings when tested under hydrostatic pressure and is caused by porous oxidized metal in the casting. The defect is revealed by a sweating of the casting under high pressure. Globules of water seep through more or less rapidly and trickle from the surface.

(8) Castings may be of poor material, too hard for machining, or defective in strength. These defects are avoided by an analysis of the material before casting.

273. Remedies for Defective Castings.—In some cases defective castings may be remedied.

(1) Strains are removed from castings by annealing. This is usually necessary only with steel castings, or chilled cast-iron castings.

(2) A warped casting may be straightened by weighting it and building a charcoal fire under it to heat it red hot. Provision must be made not to let the weight bend the casting more than is needed.

(3) A small hole caused by sponginess may be drilled out and plugged. A small blow hole or small collection of blow holes may frequently be remedied in the same way.

(4) Cracked or broken castings may in many cases be repaired by "burning on," by electric welding, or brazing.

The Steel Foundry.

274. Steel Castings.—In strength and other qualities steel castings resemble steel forgings much more than they do cast-iron castings. But for their marked superiority over cast-iron castings doubtless their greater cost would have stopped their production. Properly made steel castings are not brittle, but will stand a remarkable degree of cold bending without showing cracks or flaws. They are much stronger than wrought-iron forgings, and approach, or in many qualities equal or exceed, the elastic and tensile strength of rolled or forged steel. They are cheaper than forgings, except possibly those forgings made by the drop-forging process. Cast-steel castings are usually low enough in carbon to stand welding.

In considering the strength of steel castings, the elastic strength is highly important, as a casting is practically ruined after its elastic strength has been exceeded. A high per cent of elongation and high elastic limit are desirable. Absence of these is an indication of brittleness.

275. Steel and Iron Foundries Compared.—Although the work of making steel castings is closely associated with the steps in making cast-iron castings, yet there are several requirements of great importance in the preparation of steel moulds which mark the production of steel castings as an art by itself.

The steel foundry is generally an independent branch of industry just as are many branches for the re-manufacture of metals.

Comparing the steel and the iron foundry, their locations are alike in requirements, equipment and interior arrangement are very similar, moulds must embody the same essentials, the same requirements hold for sand used in moulding, and the tools, accessories, and most of the minor moulding materials are the same.

The differences between the requirements of moulds for making cast-iron and steel castings are differences in degree rather than

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differences in kind. These differences are due (1) to the effects of higher heat of molten steel when poured into the mould, and (2) to its greater shrinkage in cooling, for it does not expand as does cast iron, which precipitates some of its carbon.

The shrinkage of steel is about twice that of cast iron.

276. Moulds for Steel Castings.—Dry sand moulds made in iron flasks are used for steel castings, although small steel castings are frequently made in green sand moulds contained in wood flasks. The boundry between the use of green and dry sand moulds in this work depends upon the care and skill of the moulder, but castings of over a few pounds are safest and soundest when made in dry sand. A dried mould must be dried thoroughly to prevent damage from steam, and it is the practice of some steel foundries to heat green sand moulds gently over night in a drying room.

277. Particular Requirements of Steel Moulds.—The higher heat of steel when cast requires that (1) particular attention be paid to the venting of moulds, and that (2) the mould surfaces be especially treated to prevent washing away, or "scabbing," when metal is poured into them, and to prevent fusing in contact with the highly heated metal. The greater shrinkage of cast steel requires (1) that large feeding heads be attached to the heavy parts of a casting to prevent shrinkage cavities in the casting, and (2) that cores and moulds be composed of materials which will crush readily or which can be dug out to avoid shrinkage cracks.

Steel moulds are rammed up harder than iron or brass moulds.

278. Surfaces of Steel Moulds.—After the pattern has been removed from a steel mould, the face of the mould and particularly any sand projections subject to the wash of the metal, are stuck with wire nails more or less close together. The heads of these nails are often visible in the face of the mould, and their imprints may be seen on the surfaces of many steel castings.

The surface of the mould is sprinkled with molasses water or similar sticky preparation to make the sand hold together better, and a powder or wash of ground quartz or other pure silica is dusted or brushed over the entire mould surface and over the parting adjacent to the mould cavity, to make these surfaces highly refractory. The molasses water also aids to hold this silica facing, as the facing is not adhesive itself.

279. Means of Avoiding Shrinkage Cracks.—Shrinkage cracks may occur where thin and thick parts of a casting join, due to the unequal rate of cooling of the different masses of metal. These are prevented by making changes of thickness very gradual, even at the expense of making the casting heavier and necessitating machining away later of some of the extra metal.

A very common practice to prevent shrinkage cracks where two surfaces meet at an angle, is shown in Fig. 136. The sides *c* and *d* cool quicker than the larger mass of metal at the corner, and in cooling they tend to shrink away from it and to cause a fracture in the hotter and weaker metal there. To prevent fracture, the moulder cuts thin webs or gussets *b*, about 4 or 5 inches apart, in the mould. These webs cool first, keeping the sides together at the corner while the metal mass of the corner is cooling. These webs

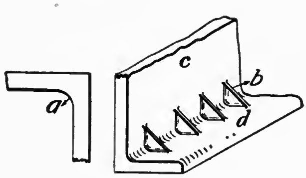


FIG. 136.

cause an internal strain by their cooling, but this is relieved by annealing the casting, and the webs are then cut away, leaving a fillet as at *a*.

280. Avoiding Surface or Interior Cavities.—The great shrinkage of steel would cause surface or interior cavities in the casting were it not fed by its runners, risers, and feeding heads. The static pressure of the metal in these insures the filling of the mould provided they are large enough in diameter to remain liquid until the casting has solidified. A feeding head is merely an extra riser over a heavy part of the casting, and the fluidity of both feeding heads and risers is prolonged by churning the metal in them with small iron rods. Often a riser or feeding head is ½ or ⅓ the weight of the casting, and is as much as ten inches in diameter for large castings.

The removal of large risers, runners and feeding heads requires considerable work, and adds much to the expense of steel castings.

An old and effective method is to saw them off with a cold steel saw, but where a shop has facilities for electric cutting, a much cheaper way is to cut them off by use of the electric arc. One electrode is fastened to the riser and the other, suitably rigged to be handled by a workman, is passed around the riser neck close to the casting. The intense heat of contact melts a groove around the riser, reducing its diameter until it can be knocked off by a sledge. The brilliancy of the arc is such that the workman must wear a metal head shield provided with black glass sight openings, and the work is done within an enclosure to keep others from looking at the arc.

Another method lately developed for such cutting is the oxy-acetylene burner.

281. Steel for Castings.—In steel works, where steel is made, castings are poured from open-hearth, Bessemer, or crucible steel, as may be required. The making of steel castings in large steel works is usually an incidential operation, as steel is made principally for rolling into various shapes, as described in Chapter V.

In steel foundries, where steel is made only for castings, a small converter is used to make steel by "blowing" pig iron melted in the foundry cupolas. This is essentially the Bessemer process. The steel-making equipment of the usual steel foundry consists of (1) two or more cupolas for melting cast iron, (2) one or more small converters (usually in America the Tropenas type of about two tons capacity), and (3) a small cupola for melting the ferro-manganese or other recarburizer which is mixed with the converter contents after blowing.

In quality, steel for castings must be low in phosphorus and sulphur, although these ingredients are not so objectionable in cast as in rolled steel. Silicon and manganese should be kept within limits, and particularly should iron oxide and dissolved gas be reduced to the lowest limits possible. The hardness of the casting, and directly its tensile strength and brittleness, depend upon the per cent of carbon contained. Hard castings contain up to .9% of carbon, medium castings contain around .5%, and soft castings contain around .3%. Most castings contain between .35% and .50%. Soft castings are hardest to obtain because of the higher melting point of low-carbon steel. This grade of castings often looks very rough. The very best steel castings contain about 3½% of nickel.

282. The Tropenas Converter.—The product of this converter is acid steel produced as in the Bessemer process except that the Tropenas converter directs its blast against the surface and not *through* the metal. Fig. 137 shows a Tropenas converter in cross-section. The lining is the same as that for an acid Bessemer converter, and the tuyeres, arranged in two horizontal rows in the side of the converter, are formed of lining-bricks with holes through them. The lower tuyeres, used throughout the blow, are called the *reaction tuyeres* and they open into the main wind box *C*. The upper tuyeres, used during the latter part of the blow, are called the *combustion tuyeres,* and open into the auxiliary wind box *D*. The advantages claimed for this converter are (1) the blast pressure is

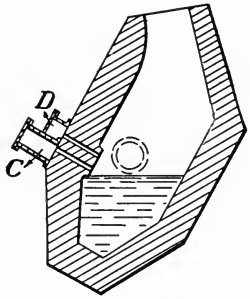


FIG. 137.—Converter for Steel Foundries.

very low (not over 5 lbs.) as it is not forced through the metal, and therefore requires a less powerful blower; (2) the surface impact agitates the metal less, causing it to take up less gas than the through blow; and (3) the combustible impurities in the metal are more completely burned.

The converter is charged with very hot metal from the cupola, the blast is admitted through the lower tuyeres, and the burning out of the impurities proceeds as in the acid Bessemer process. As the blast enters through the tuyeres, it strikes the surface of the metal at an angle, agitating it slightly, and when the flame from the mouth of the converter begins to die down, air is admitted through the upper tuyeres for a greater supply and better distribution of oxygen. The blow lasts but a few minutes, and when the flame dies

out, the recarburizer is poured in and stirred. The steel is then poured into ladles and taken to the moulds.

283. Temperature of Steel for Pouring.—The temperature of steel when poured into moulds is highly important, and varies with the size of the casting. An experienced foundry superintendent judges the right pouring temperature by simple inspection. Hotter metal is needed for small intricate castings than for large and massive castings.

If metal is too hot, it is very searching, and causes piping or cavities, and possibly shrinkage cracks, by excessive and unequal contraction in the mould. If below a certain fluidity, the mould may not fill completely or *cold shuts* may be formed. Small bits of aluminum thrown into the ladle reduce iron oxide, thus helping the fluidity of the steel.

After pouring steel moulds, they are watched to see that the mould feeds from the risers and feedings heads, and when the metal has "set," clamps are removed from the flasks, and the mould is somewhat loosened to allow the casting free contraction, yet the casting must not be laid bare to sudden chilling.

284. Annealing Steel Castings.—Because of the considerable change in form by contraction during cooling, steel castings of large bulk and particularly varying thickness, are apt to be under stress due to the contraction of a heavier and hotter part after a thinner part has cooled. Especially is this the case with castings naturally brittle from a high per cent of carbon. The stresses are removed, or at least are reduced within safe limits, by annealing.

This may be done in any kind of a brick furnace which can be evenly heated to the temperature required. After the heat has remained for a while at its maximum, the furnace openings are stopped with bricks or clay to insure slow and even cooling as the fire dies out. Castings may be covered with sand to assist in the gradual and even heating and cooling of light and heavy parts. Castings are heated red, and annealing requires from 60 to 180 hours.

The elastic and tensile strength of a casting is controlled to such a degree by annealing that many investigators are seeking to find the factors controlling this process. Method of heating, time and

temperature, all enter into the problem. Annealing furnaces need pyrometers to insure best results.

By exercising care in allowing small and medium-sized castings to cool in the moulds, the necessity of annealing may be avoided.

285. Defects in Steel Castings.—Steel castings are subject in general to the same defects named for cast-iron castings, but particularly does the manufacturer of steel castings have to be continually on guard against three classes of defects named, as follows:

(1) Cavities on the surface or hollows in the body of the casting (piping) caused by runners, risers and feeding heads too small to feed the casting as it cools. The hollows are so small at times as to resemble blow holes.

(2) Shrinkage cracks or internal strains due to unequal rates of cooling of various parts or resistance of the mould to contraction of the metal.

(3) Blow holes or small globules of gas or air enclosed in the metal. They may be due to (*a*) poorly vented or poorly dried moulds in which air and steam do not escape from the mould cavity, or (*b*) to carbon monoxide and other gases dissolved in the metal while very hot in the converter and which are thrown out of solution as the metal cools, a defect greatly remedied by the chemical action of ferro-silicon or aluminum.

One test usually specified to determine the soundness of steel castings is to suspend and strike them with a hammer, or to hammer without suspending. This does not always show the defect a casting may have.

Sometimes a cracked casting which has been annealed may be made good by welding on a piece to repair the crack.

CHAPTER X.

THE BLACKSMITH SHOP.

286. The Blacksmith and Forge Shop.—The work of shaping iron into many forms by heating and hammering is a process which has been long in vogue, and it is far more widely known and practiced to-day than any of the other metal-shaping processes. Every village, and every farming and mining community has its blacksmith shop. The simple equipment needed for blacksmith work of the cruder sort makes this process readily available at any place where heat, hammer, and improvised anvil are at hand.

Blacksmithing is, strictly speaking, a re-manufacturing process, and it is practiced independent of other shops in turning out ready for use many products of forged iron with which everyone is familiar.

In a large building and repairing establishment the work of making forgings is divided between (1) the *blacksmith shop,* where forgings are made by manual labor on the anvil as in the village shop, and (2) the *forge shop,* where large forgings are made by the steam hammer.

The forgings made in the blacksmith shop are for the most part used just as the shop turns them out, or else they may require no other finishing than a little filing or grinding. Large forgings made under the steam hammer are almost always rough shapes to be machined accurately to required dimensions in the machine shop. Examples of this class of large forgings are crank and line shafts, cross-heads, connecting and piston rods, large braces and bolts, used in marine and stationary engines. Many parts of engines subject to stresses in motion are made of large forgings because of the greater homogeneity and reliability of their material as compared with cast steel.

The largest class of forgings, as large gun parts, shafts of large engines, etc., are special products in size and quality of material, and these are made, as was outlined in Chapter V, by the steel works which produce the special ingots necessary for them.

The process of drop-hammer forging has narrowed the field of work for the blacksmith shop, and not only has the drop hammer succeeded in making many forgings formerly made on the anvil by hand, but it makes many superior and complicated forged shapes heretofore made only as iron or steel castings or cut to shape at great expense in the machine shop.

287. Materials for Forgings.—The stock for working into small forgings comes from the rolling mill as rods and bars of various sections. This material, at the present day, is principally mild steel, this having displaced most of the wrought iron used before the days of mild steel. However, many blacksmiths use only wrought iron in work which must be welded, as this material has the quality of becoming very plastic at a high heat before melting. High-carbon steel and cast iron cannot be welded on the anvil because the carbon in them begins to burn out before welding heat is reached, and because the melting point is not preceded by a helpful condition of plasticity.

Oftentimes for special work in marine use, the stock of the blacksmith shop includes rods and bars of certain bronzes which can be forged and welded as can iron.

A shop always carries in stock some bars of high-carbon or alloy-crucible steel for making metal-cutting tools.

For steam-hammer forgings, billets and blooms, of designated dimensions and quality, are ordered from the rolling mills. These are usually of mild steel, but may be of wrought iron. For high-grade forgings, nickel steel is much used.

Steel castings are occasionally heated and shaped differently from the shapes given by the mould, though this adds much to their cost and they should be annealed afterward.

288. Shop Equipment for Hand Forging.—This equipment consists of (1) a suitable forge for heating, (2) an anvil mounted solidly at a convenient working height, (3) hammers in form and weight suitable for shaping forgings to best advantage, and (4) appliances to hold and to assist in shaping material worked upon. Also, there is always more or less accessory equipment in the blacksmith shop, such as vise and bench, cold chisels, files, grindstone, taps and dies, hand-power drill, and other appliances from machine-shop equipment, employed for cold iron work.

289. The Forge.—Forges are of various forms, portable and stationary, and framed of brick or iron. Most of them use coal for fuel, but brick-lined furnaces for oil or gas fuel are now in common use. For coal-burning furnaces, the essential parts are (1) the forge-pan or hearth, into which leads a tuyere from underneath for conveying air to the under side of the fire, (2) the chimney, or exhaust hood and duct for conveying away smoke, and (3) the bellows or blower for forcing air through conduits to the tuyere.

The oil or gas-burning forge is a brick-lined box open at the top or on one side for putting in work to be heated. It is provided with a burner which blows air and fuel into the enclosed space where it burns in a continuous flame. The products of combustion usually escape into the surrounding atmosphere.

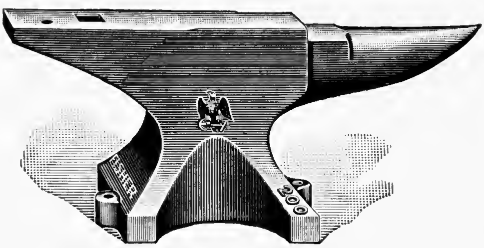


FIG. 138.—Anvil.

Attached to or beside a forge is an iron or wood quenching basin filled with water, and racks for holding tools which the smith uses in forging. A small iron poker and hooked scraper are essential fire tools.

290. The Anvil.—Fig. 138 shows an anvil of usual form. The body and horn are made of wrought iron or forged mild steel, with a 3/8-inch face of crucible tool steel welded on the body. However, some anvils are made by casting upon a tool-steel face and horn a body of a gun-metal grade of cast iron. The face and horn are cast to shape from crucible steel, and are then placed to form the bottom of a mould. They are heated to a red heat when the mould is poured to insure complete welding of the two metals. After the tool-steel face is welded on, it is hardened by heating and quenching in water and then ground to a working surface.

When a hole is to be punched in a forging, it is done over the round hole of the anvil. The square hole is for receiving the stems of anvil tools.

FIG. 139.—Hand Hammer.

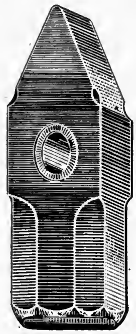


FIG. 140.—Sledge Hammer.

291. Smiths' Hammers.—These are made of a medium-carbon crucible cast steel. They must be hard though not brittle. Hand hammers weigh about two pounds, and sledge hammers weigh from 5 to 20 pounds, though for ordinary work about 10 pounds.

Fig. 139 shows a hand hammer with a *cross pene* shape of small end. Fig. 140 shows a sledge with a *straight pene* shape of small end.

Straight Lipped Tongs.

Single Pick Up Tongs.

"Gad" Tongs.

FIG. 141.—Tongs.

292. Tongs and Anvil Tools.—Fig. 141 shows three varieties of tongs much used in blacksmithing, though there are many special forms for holding peculiarly shaped forgings.

Fig. 142 shows tools used in anvil work. They are designated as follows:

(1) Top and bottom swages, for rounding.

(2) Top and bottom fullers, for necking.

(3) Hardie, for cutting off.

(4) Flatter, for smoothing.

(5) Hot chisel (thin edge), for cutting hot iron.

(6) Cold chisel (thick edge), for cutting cold iron.

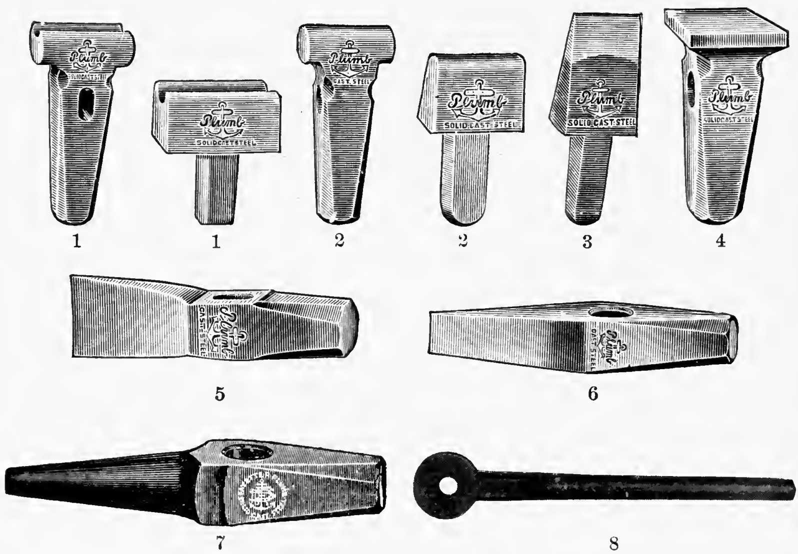


FIG. 142.—Anvil Tools.

(7) Round punch, for punching holes in hot iron.

(8) Heading tool, for forming a bolt head.

The stems of the bottom swage, bottom fuller, and the hardie, fit in the square hole in the anvil. The heading tool has a metal handle, and the remaining tools in the figure have hickory handles.

Fig. 143 shows a swage block, a very useful adjunct to the anvil in shaping and bending bars of any shape.

Many sizes of the tools shown and many tools for special work, as chain making, are not uncommonly seen in a well-equipped shop.

Anvil tools are made of a tough grade of medium-carbon crucible cast steel, and they should be harder than forgings.

293. Fuel for Use in Forges.—Up to recent years soft coal was the most extensively used fuel for forges, but petroleum residue is now much used, and natural gas is used in localities which supply it.

Soft coal is used because its gaseous constituents distil off continuously during burning and assist the solid carbon to maintain a steady fire. The coal used must be of a quality containing very little if any sulphur, and almost free from mineral matter which will not burn or which will form a pasty mass of slag or clinker in the fire. It should be a free coking coal, broken into small lumps

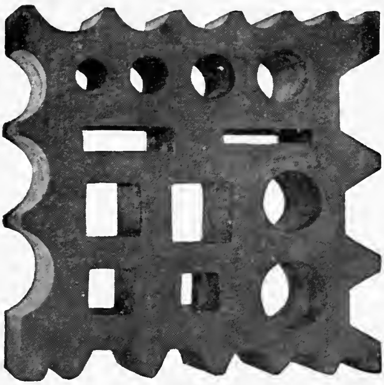


FIG. 143.—Swage Block.

which will stick together slightly during burning. The air blast is supplied in a forge to increase the rapidity of combustion in one spot, and thus supply a concentrated quantity of heat for needs of local heating.

Oil used in forges is the same as supplied for steam boiler uses, although the grades low in sulphur are preferable. To attempt the used of undistilled, or crude, petroleum would be dangerous because of the gasolene and other highly volatile constituents.

294. Heating in a Forge.—A clean fire of incandescent coal all around a piece to be forged will insure even heating. There must be a substantial layer of burning coal between the forging and the tuyere, else the oxygen of the air entering through the tuyere will burn the forging. Also the supply of air must be regulated by the

damper to avoid letting more in than can be consumed by the burning fuel, as any excess will be taken up by the hot iron, forming a scale of iron oxide over the surface.

The simple means of regulating the air and oil, or air and gas supply to oil and gas furnaces by merely turning the controlling valve of each, makes these forges superior to coal forges.

The degree of heat to which a forging should be raised varies somewhat for different kinds of work. Welding requires a high heat to bring the parts to be joined near the fusing temperature, but for shaping it is sufficient to bring the piece to a red heat. A large forging should be heated as bright as can be without burning and it is often heated yellow because fewer heats are necessary and the more plastic condition at high heat insures the hammer impact reaching further into the mass of metal. The finishing of work at a low red heat shapes the surface, and the blows then should not be heavy. No forging should be done below a red heat, except that light blows may be given to smooth the surface.

The heating of forgings is a part of the subject of the heat treatment of steel, which is now a matter of careful study among those experienced and interested in steel working. Wrought iron is less affected by overheating because it has no carbon to be burned out, and is not subject to the internal crystalline conditions to anything like the degree affecting steel, if at all.

295. Terms Commonly Used in Forging.—Among the terms used may be mentioned the following:

(1) Upsetting is the increase in thickness and decrease in length produced by hammering a hot piece of metal on the end. Upsetting is resorted to for forging bolt heads, and for forming a bulk of metal as ample stock for further heating and hammering operations in welding, etc.

(2) Drawing out is the opposite of upsetting and is used when work is to be pointed or made smaller in cross-section.

(3) Scarfing is the tapering of two ends of metal so that they may fit together at their surfaces of contact as if one continuous piece.

(4) Swaging is the reducing of cross-section, and finally the shaping and finishing a bar or rod by use of the swage block or by use of the top and bottom swages on the anvil.

296. Measuring Stock for Forging.—Fig. 144 shows two dimensioned sketches such as would be given a blacksmith for making an angle and a ring. To cut stock to the exact length for the angle, take the length of the *neutral axis ab,* which is practically 15 inches in this case. Likewise, stock for the ring is cut to a length equal to the length of the neutral axis plus an amount needed for scarfing and lapping for a weld. In homogeneous bars or plates of malleable metals, the neutral axis is practically in the middle plane, and bending stretches metal on one side of this plane about as much as it compresses metal on the other side.

297. Welding.—This process of joining together two pieces of iron has long been practiced in blacksmithing, but is now by no means confined to the blacksmith shop nor to the metal used therein.

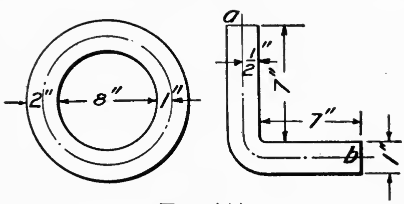


FIG. 144.

In welding wrought iron or mild steel in the blacksmith shop, care is required to heat both pieces evenly. Mild steel must be heated and worked with skill and judgment in welding, as its temperature range between the time it becomes cohesive and the time it melts or begins to oxidize rapidly is not as great as the corresponding temperature range of wrought iron.

To assist welding a flux is used. The surfaces of metals brought to a welding heat are unavoidably oxidized more or less, *i. e.,* scale is formed on them. If this is allowed to remain, it prevents contact of metal to metal, thus preventing a weld. The flux is sprinkled in the ends at about a yellow heat. This melts and forms a film over the hot metal protecting it against further oxidation and causing the oxide formed to melt at a low heat. The liquid oxide and flux are readily displaced as the metal is hammered into contact. Scale formed on wrought iron melts at about its welding temperature, hence some smiths may not use flux for wrought-iron welding.

Fluxes commonly used are silica (sand), borax, or sal ammoniac. A borax flux should be first fused to get rid of its water of crystalization and then it does not bubble when powdered and sprinkled on the hot metal.

Anvil welding requires preliminary shaping of the two surfaces to be welded. The forms of welds much used are as follows:

(1) *Faggot weld.* A frequent example of faggot welding is that used to make a large mass of metal in a bar as shown by the doubled part in Fig. 145.

FIG. 145.

FIG. 146.

(2) *Lap weld.* Fig. 146 shows the ends of two pieces prepared for a lap weld. Their contact surfaces are made convex to force out any scale or dirt as the weld is hammered together.

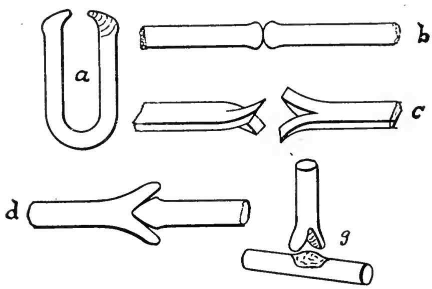


FIG. 147.

(3) *Link weld.* This is a lap weld much used in chain links, eye bolts and ring welding, and is shown at *a,* Fig. 147.

(4) *Butt weld.* The two pieces are shaped with convex ends as shown at *b,* Fig. 147.

(5) *Split weld* for thin material. The form, shown at *c,* is used because the two pieces can be jammed together quickly on drawing them from the fire and hammered without loss of time, as the pieces cool quickly.

(6) *Split weld* for heavy material. Pieces shaped for this weld (*d,* Fig. 147) give much bearing surface within a small radius. This is much used in welding together wrought iron and mild

steel. A bulk of metal holds its heat longer for welding, and much bearing surface gives a greater per cent of strength of the weld as compared to the strength of the solid piece.

(7) *T weld.* The pieces for this weld are shaped as shown at *g,* Fig. 147.

298. Hardening and Tempering at the Forge.—The forging, hardening and tempering of steel tools for cutting metals have long been practiced as a part of blacksmithing. The process used by blacksmiths to give an edged tool the correct degree of hardness is accomplished in two steps vaguely designated as "tempering." To illustrate blacksmith-shop hardening and tempering, which, though crude, is highly useful and very convenient, an example of hardening and tempering a cold chisel will be given:

Having forged the cutting end to shape, place this end in the fire and heat about half the length of the chisel to cherry red (the critical temperature, as near as can be judged). Plunge most of the red hot part into water, holding it still until cold, then withdraw and quickly rub a bright metallic spot near the cutting edge with a piece of grindstone or other abrasive material. This quenching gives the cutting end the maximum hardness which can be given it, but this is too hard for use, and the heat left in the unquenched part of the chisel is now used for the purpose of tempering this extreme hardness, or "drawing the temper."

Holding the chisel in the tongs, watch the gradual changes of color on the rubbed spot, as the heat travels down from the unquenched end. As soon as the color reaches that denoting the hardness desired (dark purple in this case), plunge the whole chisel at once into water to prevent further "drawing of temper."

The water must not be extremely cold, as the sudden change of temperature may be great enough to cause small cracks over the surface of the steel.

299. Color Table for Judging Hardness.—The first color observed after rubbing a bright spot on a piece of quenched steel is a light straw, denoting the greatest degree of hardness possible for that particular piece of steel. As the heat travels into the quenched end, the hardness decreases, as denoted by the change of colors in the order of light, medium and dark straw, light and dark purple, dark and light blue. These colors are *temperature indicators,* and as the

reduction in hardness of the steel is dependent upon the amount of annealing which the hardened end gets from the heat in the other end, these colors correspond with degrees of relative hardness in regular order. A color, purple for example, does not indicate the *same degree* of hardness in all grades of carbon steels, as the hardness in different carbon steels at a given temperature depends upon the contained carbon.

300. Hardening of Alloy-Steel Tools.—The alloy steels are so various in composition that no general rule can be given for their hardening. The best method is to follow the directions given by the maker of each grade of this steel, and not attempt to harden all grades by the method one may be familiar with for hardening any particular alloy. However, many alloy steels are hardened by heating to a white heat and cooling in a blast of air—less rapidly than by quenching.

301. Influence of the Cooling Medium in Hardening.—The practice of using water, brine, oil and other liquids for quenching a steel tool after heating for hardening, varies with different blacksmiths. As was previously mentioned, two of the factors controlling the hardness of a piece of quenched steel are the rapidity of cooling and the range of temperature through which cooled. These may be combined as one condition, viz., the range of temperature through which a piece of steel is cooled in a given time. In any cooling liquid this condition depends (1) upon the difference in temperature of the steel and the liquid, and (2) upon the rapidity with which the liquid will conduct away the heat imparted to it by the metal. It is seen that the 2d item depends upon the ability of the liquid as a conductor of heat, upon its specific heat, and whether or not its vapor forms around the hot metal or whether a sticky film, as of oil, forms around the metal from charring. Experience is best to determine all these factors, and there is no mysterious virtue about any of the cooling media.

302. Annealing in the Blacksmith Shop.—Occasionally it is necessary to take the temper from a piece of tool steel for forging into another shape, *i. e.*, the steel is to be softened. It is heated to a red heat and is placed between two heavy pieces of pine board. Weighted down, or pressed together in a vise, the steel soon burns a cavity in the wood, and as the two boards come together they com-

pletely bury the steel, shuting off all oxygen and stopping further burning. The charred wood surrounding the steel allows it to cool only very slowly, and in a few hours the metal is cold and soft.

A red hot piece of steel may be softened by burying it in hot sand. The object is slow and even cooling. Some alloy steels cannot be softened by any known means after they are once hardened.

303. Equipment of the Forge Shop.—As this part of the blacksmith shop is intended for heavy work its principal equipment is one or more steam hammers of the small single frame type or of the heavy double frame type. Other essential equipment includes:

(2) Tools and holding appliances to assist in shaping the forging and in holding the billet forged.

(3) A suitable furnace, preferably oil or gas fired, for heating billets.

(4) An upsetting machine (not always installed) which works much like a rivet-heading machine in squeezing a length of red-hot metal into a shorter and larger bulk.

304. The Steam Hammer.—Steam hammers are *single acting* when the hammer is raised by steam and falls by gravity alone; or are *double acting* when the hammer is raised and forced down by steam.

The smaller hammers have single frames and the larger hammers, as shown in Fig. 148, have double frames. This view shows a 2500-lb. hammer, *i. e.,* one whose hammer and moving parts attached thereto weigh 2500 lbs.

The hammer *H* is raised and forced down by steam acting on a piston in the cylinder *C*. One of the levers at the side governs the steam supply to the hammer, and the other controls the rapidity and force of the blows. The hammer oscillations synchronize with the controlling lever movements, and an experienced man or boy can regulate the force of the blow with great nicety. The dies *DD* are keyed to the hammer and to the anvil cap *A*.

305. Appliances Used with the Steam Hammer.—Blooms and large billets are held during forging by a chuck and porter bar, or by a porter bar clamped to one end of the forging. Smaller billets are gripped by heavy tongs made to conform to the size of the billet end. The combined weight of billet and tongs is balanced in the loop of an endless chain hung from the crane.

The principal steam-hammer tools are as follows, shown in Fig. 149:

(1) The *hammer-chisel,* for cutting hot iron nearly in two from one side.

(2) The *snapping bar,* round at one end and triangular at the other end, for finishing, from the opposite side the cutting begun

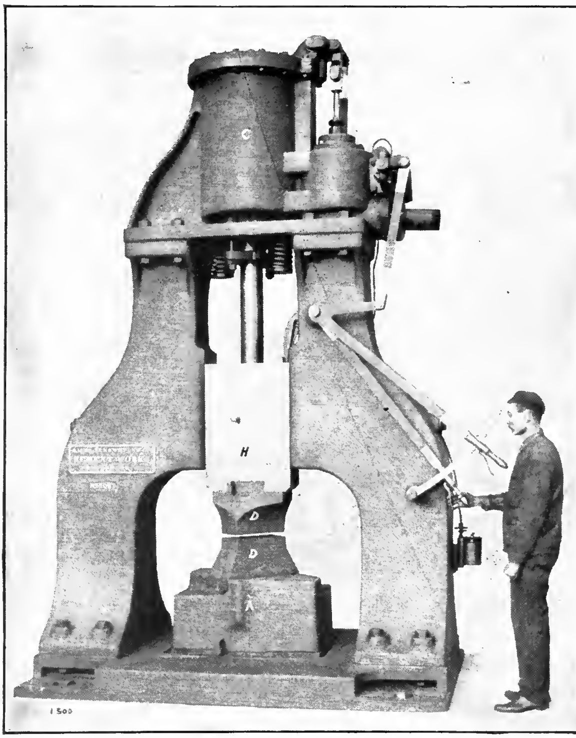


FIG. 148.—Steam Hammer.

by the hammer-chisel. To cut completely through with the chisel would injure the chisel against the anvil.

(3) The *necking tool,* for making a square or filletted shoulder.

(4) The *fuller bar,* a round bar for reducing and grooving forgings.

(5) The *tapering and fullering tool,* used as shown at 5a.

(6) The *set,* a square bar for squaring corners in narrow parts of a forging.

(7) The *spring swage.*

(8) The *punch.*

A tool is held against the forging and it receives the blows of the hammer. The handles of these tools are from 3 to 6 feet long, of iron.

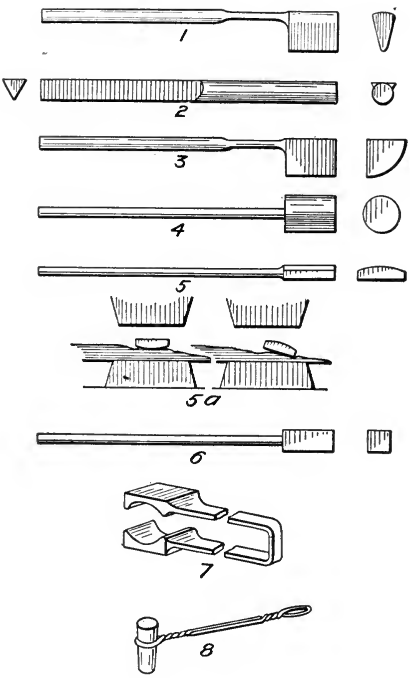


FIG. 149.—Steam Hammer Tools.

306. Heating Furnaces.—The open forge is not well adapted to steam-hammer work, but some form of closed furnace is necessary to give the required amount of concentrated heat. Oil, gas or coal furnaces are much used, with preference for the oil furnace because of its ready control. Oil furnaces of similar type to that shown in Fig. 50, but usually smaller, are well adapted to forge shop use.

307. Notes on Steam-Hammer Forging.

(1) Upsetting in large forge work may be done by holding the heated billet between the hammer and the anvil dies and bumping it with a battering ram known as a "tup" or "monkey." This is a heavy mass of iron with a smooth end and a long horizontal handle. It is suspended from the roof, and is swung like a pendulum so that it strikes the billet on end.

(2) Metal should be forged only at a red heat, though light blows for surface finishing may safely be given at a blue heat. Forging nearly cold iron is not advantageous and iron so forged should be annealed.

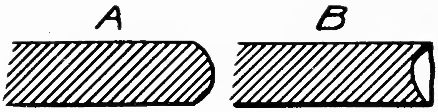


FIG. 150.

(3) The energy in a small hammer forced at high speed against a forging may be made the same as that in a large hammer forced at a lower speed, but the effect of the blow on the forging is not the same. A quickly delivered blow is superficial in its effect, while a slowly delivered blow from a heavy hammer is more like the squeeze of the hydraulic press, and is deeper felt. The particles of metal have time to re-arrange themselves under the slower speed of the heavy hammer.

(4) The effects of cold or hot forging, and of light or heavy hammers as mentioned in items (2) and (3) are often shown in finished forgings, sometimes to the extent of damaged parts. For example, the piece *A*, Fig. 150, shows how the edge of a forging looks which is forged at a good working heat and the hammer blows are felt entirely through the piece. *B* shows that the forging was not hot enough, or the hammer was too light, or both.

CHAPTER XI.

THE MACHINE SHOP.

308. Scope of Machine-Shop Work.—The machine shop is equipped for the work of finishing castings and forgings to exact form and dimensions. This work is done principally by means of machine tools which cut off superfluous metal, and to a far less degree by chipping, filing, and scraping with hand tools.

In addition to finishing castings and forgings, there are made in the machine shop many articles for particular or general use from bars of iron, steel, brass and bronze supplied from the rolling mill.

An important supplementary work of this shop is that of assembling the finished parts of an engine or other machine and fitting them together in complete form ready for use. This assembling is done in the erecting shop where all parts composing a machine are brought to a final adjustment.

It will be noticed that the word "work" is much used in the machine shop to designate a forging, casting, or other piece of metal to be machined, *i. e.,* finished to shape by means of machine tools.

309. Machine-Shop Practice.—The time required for work of such accuracy as is done in the machine shop, and the high cost of skilled labor for efficient work makes machine shop processes very expensive—often excessively so. Modern competition has brought close attention to the desirability of avoiding machine-shop work and of doing what can be done to save time and labor where this grade of work cannot be obviated.

To avoid machine-shop expense, particular effort is now directed to making castings smoother, and many metal articles shaped by cold or hot pressing are used in place of machine-shop products cut from solid metal.

In the machine shop, the work of which is not likely to wane in this age of metal, particular attention is given (1) to placing at the disposal of the highly skilled machinist such drawings, tools,

appliances, machines and attachments as will enable him to accomplish most in a given time, and (2) to employing perfected machines, tools, etc., so that efficient metal cutting may progress at as rapid a speed as possible.

Modern practice requires that drawings be made clear and amply dimensioned, tools be of highest quality and kept ready for use, machines be kept clean and adjusted, and in short that every movement of the highly skilled men be toward accomplishing something definite in furthering work and that all unnecessary movements be eliminated. To carry out so refined a system, the highly paid machinist must be directed in the best methods for doing a given piece of work by an efficient and experienced shop superintendent, and all that can be done through preliminary preparations or otherwise by less expensive labor is done to save the time of the highly paid man. The highly paid men are selected and developed because of their aptitude for their work, and judgment must be exercised in their selection.

Much has been written on the determination of the practical rate at which metals can be cut, and no little value has been derived from efforts along this line. It may be said that a machine should be run at as great a cutting speed as the work, the tool, and the machine will safely stand in continued practice.

It is well to understand that there are, in machine-shop work, different degrees of refinement in cutting down and finishing to exact dimensions, according to the different degrees of error incident to various methods and classes of machines.

310. Machine-Shop Equipment.—The equipment of a machine shop naturally depends upon the size and variety of work it has to do. There are different sizes of machines of the same kind for machining different sizes of castings and forgings, also there are different kinds of machines for doing the same kind of work in different grades of refinement. An economic consideration is to have as few machines as possible to do as great a range of work as possible, and this is best accomplished by choosing high-grade machines which are not only adapted to variety of work, but are also able to stand the durable test of producing good work in minimum time. Fig. 151 shows the general arrangement of a large machine shop.

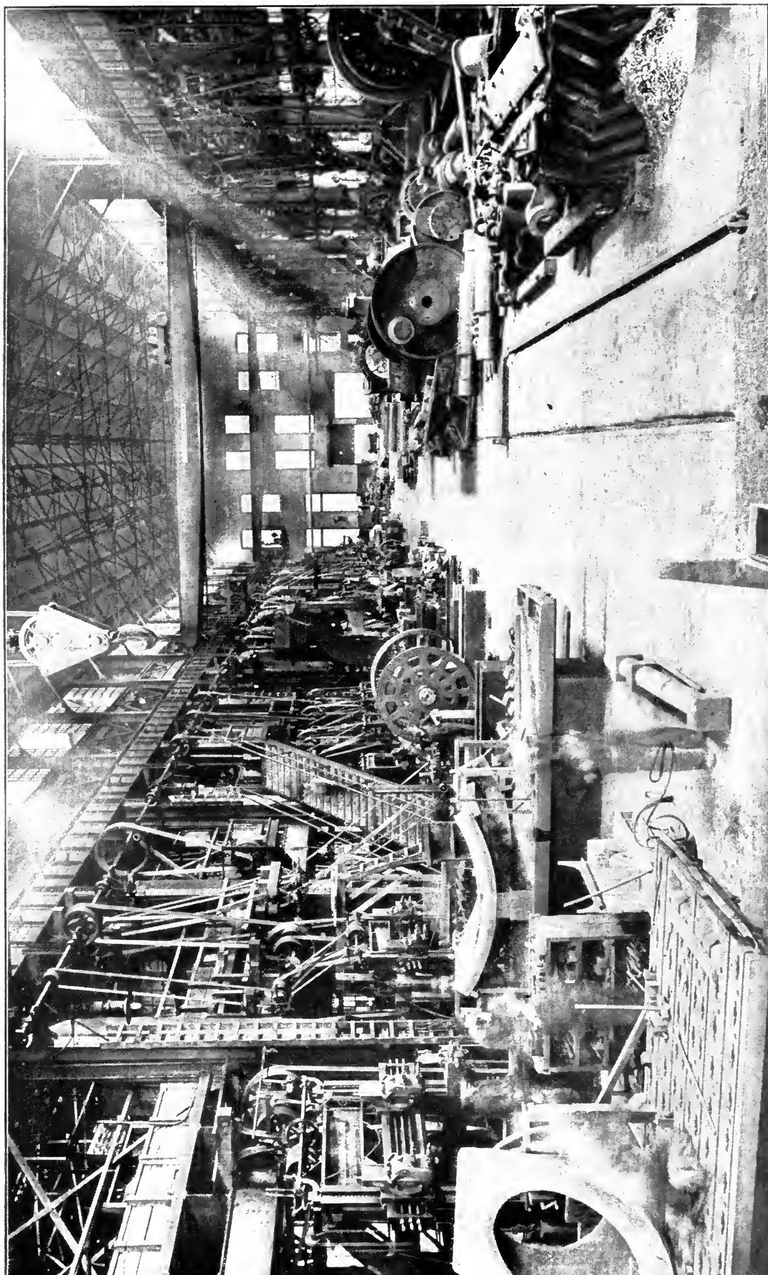


FIG. 151.—Machine-Shop Interior.

The metal-cutting machines of a machine shop are known as *machine tools* and the work done by them is known as *machining*.

The principal equipment of the machine shop is as follows:

(1) Several types of machine tools, and their cutting tools.

(2) Vise benches equipped with suitable vises for hand work and tools for chipping, filing, scraping, hand-thread cutting, etc.

(3) Small tools for measuring, trying, adjusting, etc.

(4) A laying-off table, also called a marking-off table for laying out and marking work preparatory to machining it.

(5) Portable tools worked by hand or driven by compressed air or electric power.

(6) Crane and other appliances for lifting and transporting heavy work.

(7) A tool room where all tools are kept when not in use.

311. Marking Work to be Machined.—An important preliminary in a machine shop is the lying off and marking of work. Forgings, castings and other work to be machined must be marked to indicate the location of holes to be drilled, the axis or axes of hollow parts to be bored out, and in general the limits which guide the machinst in cutting away superfluous metal to bring the work to the finish and dimensions required by the drawing. For example, Fig. 152 shows a casting of two small cylinders cast in a single piece for a steam-launch engine. This casting is in the rough just as it was received from the foundry. The two pieces of wood *WW* have been placed in the cylinder ends to aid in marking. The casting must be so marked that the machinist can bore the cylinders to bring the axes the required distance apart, face the cylinder ends to give the cylinders the required length, and in short machine off all surfaces which require machining, and drill all holes, as required by the drawing.

The marking must be done from some point, line or plane of reference which is usually chosen to agree with the axes of reference shown on the drawing. From this point, line, or plane, all holes and machined surfaces are located on the work.

In the casting here shown a plane of reference is chosen which includes the axes of the cylinders as determined by the *outer*

surfaces of the cylinders. This plane is located on the casting by the line *KLMK*, which completely girdles the casting. The line is scratched by a scriber and further marked at intervals by the center punch to avoid its obliteration. The axes of the two cylinders are then located and marked by aid of the wood pieces *W*, and from these axes all other marks are located. All dimensions are supplied by the drawings.

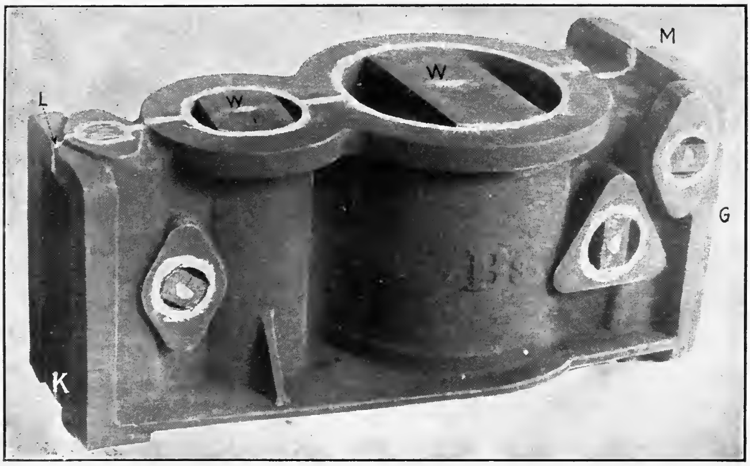


FIG. 152.—Casting Marked for Machining.

Castings and forgings are often whitewashed or chalked where their reference planes are to be marked, as this helps the workmen to see the marks readily.

The machining on the casting here shown is begun by planing the face *MG* and then the face *LK* of the two steam chests. These finished surfaces give convenient parallel planes for the transfer of measurements. Also the face *MG* forms a base for securing the casting on the machine which bores the two cylinders.

312. The Marking-Off Table.—To afford means for marking work accurately preparatory to machining it, a marking-off table is provided. Certain measuring and marking tools, and suitable blocks for supporting the piece to be marked, must also be provided.

Fig. 153 shows a small marking-off table made of a ribbed slab of cast iron supported firmly on four posts. The top, sides and ends of the slab are planed smooth and at right angles one to another. The table is placed in a permanent location in the shop,

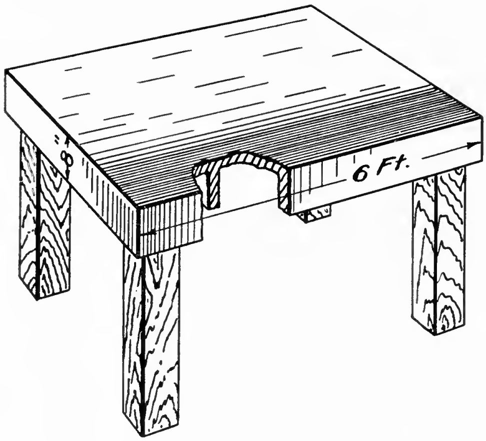


FIG. 153.—Marking-Off Table.

where it is firmly supported, and its top is adjusted accurately horizontal.

For very large work, a table may be made of several slabs placed at or near the floor level and supported on a foundation especially built to hold them level.

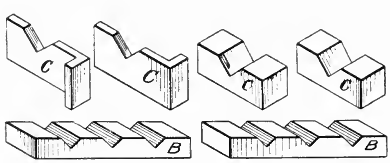


FIG. 154.—Chocks of Marking-Off Table.

313. Tools and Appliances for the Marking-Off Table.—To support a piece of work so that its chosen plane of reference may be parallel or perpendicular to the top of the table, a number of chocks and bars are used. Fig. 154 shows specimens of chocks *C* and of rectangular bars *B*. These are used in pairs and each pair must be exact counterparts.

Among the tools much used on the marking-off table are the following:

(1) *Steel rule* (Fig. 155). Made in various lengths. Opposite faces and edges are ground parallel.

FIG. 155.

(2) *Straight edge.* A long steel rule without graduations. Used to test plane surfaces and to establish straight lines as references for measurements.

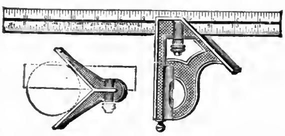


FIG. 156.

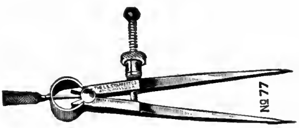
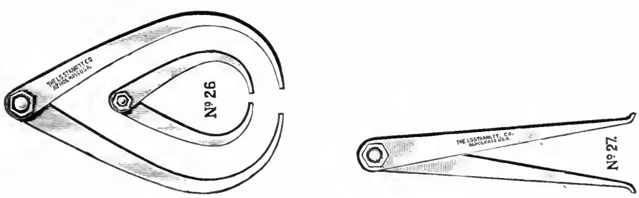


FIG. 157.

(3) *Combination level and square* (Fig. 156.) Used as a square and a level. The auxiliary center head is used to locate the centers of cylindrical work. The ordinary steel square is also much used.

(4) *Dividers* (Fig. 157).



Outside. Inside.

FIG. 158.

(5) *Firm-joint calipers* (Fig. 158). For measuring diameters, thicknesses, etc.

FIG. 159.

FIG. 160.

(6) *Center punch* (Fig. 159). This marks holes to be drilled, and marks points for locating lines on work.

(7) *Scribers* (Fig. 160). These have hardened steel points for scratching lines on metal.

(8) *Surface gage* (Fig. 161). This is used in adjusting work on the marking-off table, and for locating points or lines on the work. It consists essentially of a base, a post and a scriber. The under side of the base is planed to rest firmly on the table, and is grooved to rest symmetrically on a cylindrical surface. The scriber and post are so mounted and controlled by clamp screws that the

FIG. 161.

scriber points may be adjusted to any position desired within the reach of the instrument.

314. Refined Measuring in Machine Work.—The machine shop is the shop on which devolves the requirement of finishing work to specified dimensions within very small limits of allowable error.

The discerning of small differences in physical measurements is dependent upon the degree of refinement of measuring instru-

ments, upon variations of temperature, and upon the delicacy of the sense of touch.

All products turned out by the machine shop do not require the same degree of exactness in finished dimensions, and it would be a needless expense to finish all work with the same high degree of precision required for some grades of work. Most of the refined finishing to a particular dimension is done not closer than $\frac{1}{1000}$ of an inch. A drawing of a piece of work which is to be finished with especial care for making a close fit must state limits of error allowable and on which side of the given dimension this is allowed.

A wheel hub may be forced or driven tightly on its shaft. This is a *driving* or *forcing* fit. If the hole in the hub is bored slightly smaller than the diameter of the shaft, the hub may be expanded by heat until it fits over the shaft. On cooling it grips the shaft and makes a *shrinkage* fit.* A shaft may fit more or less closely in the bearing in which it revolves. If the fit is not too tight to prevent free motion, it is called a *working* or *sliding* fit.

Forcing fits are made by hydraulic forcing presses, or by the pull of heavy bolts.

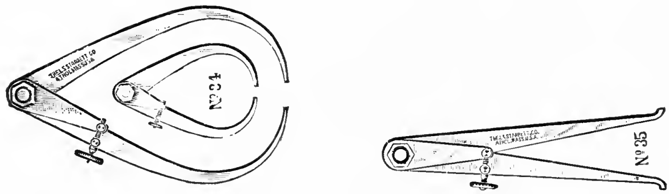
The degree of refinement necessary in a working fit for any moving part of a machine depends upon the size and degree of refinement needed in the machine. The main bearing of a marine engine is usually adjusted to about .012 inch. The main spindle of a machine lathe is about .002″ smaller than the bearing in which it revolves, and a very accurate grinding machine is adjusted as close as the metal of a carefully ground shaft and bearing can come together without gripping.

315. Tools for Measuring.—The steel rule is the simplest form of measuring tool used in the machine shop. It cannot be used, however, for measuring lengths smaller than can readily be discerned by the eye. For such measurements various forms of calipers and gages are used. The accuracy of these depends upon the sense of touch.

* A table of allowances for forcing and for skrinkage fits is given in Par. 441, Appendix.

The various forms of calipers and gages for accurate measuring are as follows:

(1) *Firm-joint calipers* (Fig. 158).

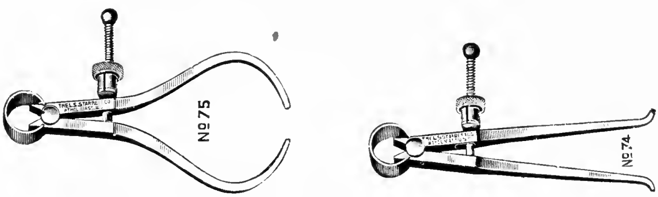


Outside. Inside.

FIG. 162.

(2) *Screw-adjusting calipers* (Fig. 162).

(3) *Spring calipers* (Fig. 163).



Outside. Inside.

FIG. 163.

(4) *Inside gages* (Fig. 164). This instrument consists of a sleeve which holds rods of different lengths for measuring inside

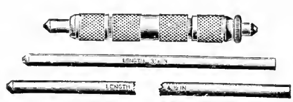


FIG. 164.

diameters of large cylinders. A threaded nipple on one end of the sleeve provides a means for fine adjustments.

FIG. 165.

(5) *Depth gages* (Fig. 165). For measuring depths. The sliding head is clamped on the rule at the point which marks the depth.

(6) *Fixed gages.* Fig. 166 shows one of several forms of fixed gages for measuring diameters within certain limits of error. The gage here shown is for measuring a hole of 1″ diameter, with an

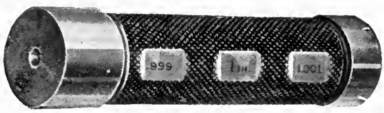


FIG. 166.

allowable error of plus or minus .001″. The end marked .999 should go through the hole; that marked 1.001 should not enter the hole.

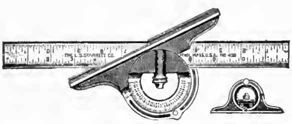


FIG. 167.

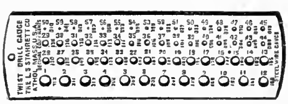


FIG. 168.

(7) *Micrometer caliper.* Adjustable for refined measuring. See Fig. 170.

FIG. 169.

Closely akin to the tools just mentioned are others much used in the machine shop. A list of them includes the following:

(8) *Protractor for measuring angles* (Fig. 167).

(9) *Drill gage* (Fig. 168). For measuring diameters of drills.

(10) *Wire and sheet-metal gage* (Fig. 169).

316. The Micrometer Caliper.—This instrument, a type of which is shown in Fig. 170, is used for measuring thicknesses and external diameters. It is the instrument of the greatest degree of precision used in machine-shop measuring.

Most micrometer calipers are made to show, on a graduated stem or barrel, readings of measurements to $\frac{1}{1000}$ of an inch, or to $\frac{1}{100}$ of a millimeter if graduated in the metric system. Some of these instruments are supplied with verniers for showing readings varying by $\frac{1}{10000}$ of an inch, but measurements of less than $\frac{1}{1000}$ of an inch are seldom used.

Material is measured between the points *B* of hardened steel, one of which is fixed in the half-round frame. The enclosed end of the spindle *C* is screwed into a fixed sleeve *A*, and when the

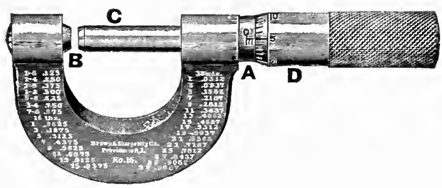


FIG. 170.—Micrometer Caliper.

spindle is turned, its threads cause it to move in the direction of its length. These threads have a pitch of 40 to an inch, hence one turn of the spindle moves it $\frac{1}{40}$ of an inch. The sleeve *A* is about as long as the distance between the ends of the frame. A hollow thimble *D* fits neatly over the sleeve, and the right-hand end of the spindle is fastened to the bottom of the thimble so that the thimble is used to turn the spindle and to gage its movements.

The tapered edge of the thimble is divided around its circumference into 25 equal parts, and a line along the sleeve *A* is graduated into divisions of $\frac{1}{40}$ of an inch. The first of these graduations is marked zero.

When the space between the measuring points is closed, the zero line on the edge of the thimble falls on the line along the sleeve, and as the thimble is turned $\frac{1}{25}$ of a revolution (or one of the

graduations on its edge) it separates the points $\frac{1}{25}$ of $\frac{1}{40}=\frac{1}{1000}$ of an inch. In this way the readings of $\frac{1}{1000}$ of an inch are observed.

Micrometer gages similar to Fig. 164 are made for refined measurement of internal diameters.

317. Machine Tools.—A list of machine tools for a well-equipped shop is as follows:

(1) Lathe.
(2) Drilling machine, commonly called a drill.
(3) Planer.
(4) Shaping machine or shaper.
(5) Milling machine.
(6) Boring machine or boring mill.
(7) Slotting machine.
(8) Pipe cutting and threading machine.
(9) Tool-sharpening equipment.
(10) Metal saws.
(11) Forcing presses.

There are several sizes and types of each of these classes of machines. The differences in the several types of one class consist of durability of make, rapidity and degree of accuracy of work done, and range of adaptability to various kinds of work.

Some shops may have machines other than those here named for special or unusual work, though many shops have only Nos. 1, 2, 3, 4, 5 and 9, and even a considerable variety of work can be managed with lathe, drill and planer.

The best means of driving machine tools is by means of an electric motor for each machine.

318. The Lathe.—In this machine, as in the wood lathe, work revolves about a fixed axis between the centers and the cutting tool moves either (1) parallel to the axis, cutting a cylindrical or spiral surface; (2) perpendicular to the axis, as in cutting the end of a cylinder; or (3) in any combination of the two directions named, cutting any variety of surfaces of revolution. The cutting of screw threads is done on the lathe.

Fig. 171 is a cut selected to show the principal features of a lathe of medium size. The main parts are:

AA. Bed.	*C*. Tail stock.
B. Head stock.	*D*. Carriage.

Work is suspended between the centers *PP*, and is driven by a dog, as shown in Fig. 172; or both centers are dispensed with and flat work is secured to a chuck or a face plate screwed on the spindle-end in place of the small face-plate *F*. The larger face plate, under the lathe, is marked *E*.

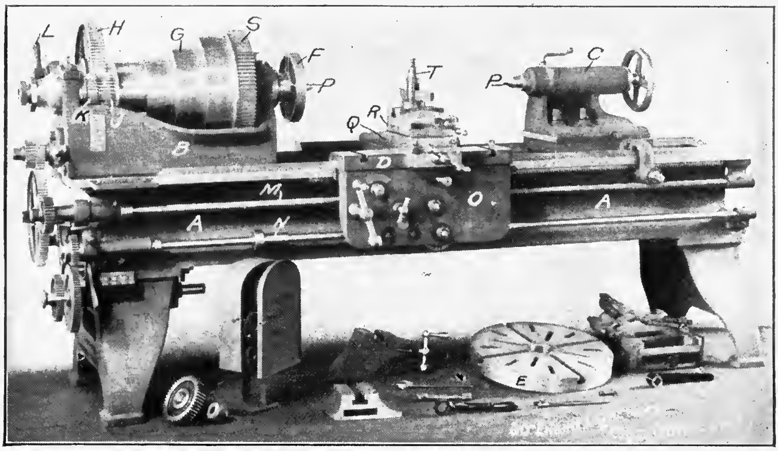


FIG. 171.—Engine Lathe of Medium Size.

The head stock carries a hollow steel spindle on which are keyed the gear wheel *S* which drives the spindle, and the small gear wheel *K* which drives the feed and screw-cutting gear at the left of the machine. The cone wheels *G* and their small attached gear wheel *J* are not attached to the spindle, but the cones drive the spindle either directly by means of a small sliding bolt which attaches them to the wheel *S*, or indirectly through the back gear. The back gear consists of a spindle supported on the head stock parallel to the main spindle, on one end of which is fixed the large gear wheel *H* and on the other end is fixed a small gear wheel not visible. The wheels of the back gear may be thrown in or out of gear with *J* and *S* by a lever *L*, and

when they are in gear, the bolt connecting the cones with S must be dropped out of its driving notch. The cone G is driven by a belt from a corresponding cone over head. The back gear gives slower speed and greater power.

The tail stock carries the dead center which may be moved forward or backward by the hand wheel for adjusting it to hold work in the lathe. The tail stock may be clamped at any position along the bed. For supporting a bar which is to be cut tapered, the dead center may be moved perpendicular to the length of the bed.

A tool is shown clamped in the tool post T. Its cutting motions are derived from the leading screw M or from the feed rod N.

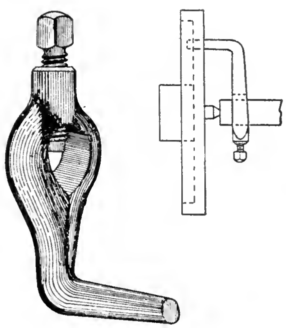


FIG. 172.

The leading screw is used in cutting threads. Any desired combination of change wheels may be placed in gear at the left to give any desired speed to the tool in relation to the speed of the lathe.

The carriage D moves along the shears or top of the bed, and the various attachments on the apron O serve to facilitate the quick adjustment and to regulate the various motions of the tool.

The compound slide rest, consisting of the two parts Q and R, carries the tool post and governs the motions of the tool other than in the direction along the lathe bed. The part Q travels perpendicular to the lathe bed, and the part R is mounted on a vertical pivot in Q which enables its slide to move the tool in a line making a greater or less angle with the direction of motion of the part Q.

The term back lash is frequently heard in speaking of machine tools, and particularly of lathe gearing. This is the slack motion noticed when reversing a train of gear wheels, due to the loose fitting between the teeth of wheels which mesh together.

319. Varieties of the Lathe.—Lathes are designated according to their different types. Among these are (1) hand lathes; (2) machine lathes; (3) gap lathes, and (4) turret lathes.

The hand lathe was mentioned with the machinery of the pattern shop. This lathe is frequently made small enough to be mounted on a bench and is called a *bench lathe.*

The machine lathe, a type contrasted with the hand lathe, cuts metals by a tool fastened on the lathe carriage. A small machine lathe may be driven by foot power and is called a *foot lathe.* A

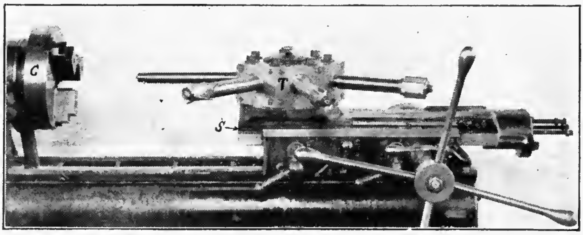


FIG. 173.—Turret of a Turret Lathe.

machine lathe is designated as a *screw-cutting* lathe when it is equipped with a leading screw and change wheels for cutting threads.

Many small lathes have no live centers nor tail stocks. A chuck is screwed on the main spindle to hold a rod which is turned to shape as in the screw-cutting machine. This type is called the *chucking lathe.*

Large machine lathes are built to run at suitable speed for rapid cutting made possible by high-speed steel, and are designated as *high-speed lathes,* confusing them with small lathes run at high speed.

A very important modification of the machine lathe is the *gap lathe.* This lathe is built to be of use through a very wide range of ordinary work, and is intended for a shop of limited equipment. It differs from the lathe described in the preceding paragraph by

having a gap in the bed just under the end of the main spindle to provide for carrying a very large face plate which holds flat work of large diameter. The lathe bed is very deep and is made in two sections divided horizontally. The upper section, which carries the carriage and the tail stock, may be slid along the lower part of the bed to open the gap under the edge of the face plate.

The feature of the turret or monitor lathe is shown in Fig. 173. The tail stock is displaced by a turret *T* which carries several tools which are used in consecutive order on the piece of work held in the chuck *C*. The turret is mounted on a vertical spindle

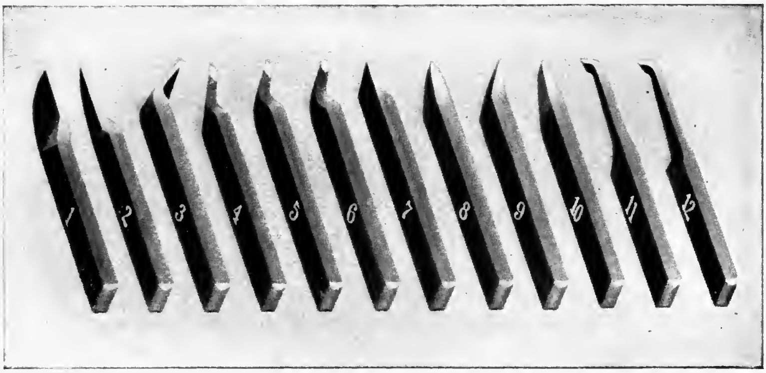


FIG. 174.—Lathe Tools.

on the slide *S*. This slide is moved to carry the tools into contact with or away from the work by the long hand-bars.

This lathe saves much time in changing tools.

320. Lathe Tools.—Fig. 174 shows the different shapes of tools ordinarily used in lathe work. These are made of high-carbon steel, or preferably of self-hardening alloy steel for heavy work. The cutting ends are forged, hardened, tempered and ground. They are designated as follows:

(1-2) Left and right-hand side-tools.
(3-7) Bent and straight cut-off tools.
(4-5) Right and left-hand diamond points.
(6) Fillet or round-nose tool.
(8) Threading tool.

(9) Bent threading tool.
(10) Roughing tool.
(11) Inside boring tool.
(12) Inside threading tool.

The diamond-point tools, Nos. 4 and 5, are about superseded by a round-nosed tool shown in Fig. 175 which is superior for size of chip, resistance to wear, and smoothness of cut, particularly on heavy work. This tool shows its advantages best when made of high-speed steel.

Because of the high cost of alloy steels used for tools, much expense is saved by having merely a cutting end of alloy steel held in a tool holder. These holders are in many styles to suit the shape of the cutting end.

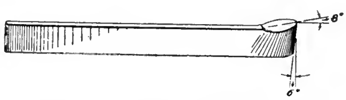


FIG. 175.—Round-Nose Tool.

Many special tools are devised for use in turret lathes, as these lathes do special work and do not use the ordinary lathe tools.

321. Lathe Attachments.—Several attachments are provided to enable a lathe to be used for various kinds of work. The most important among these are the *face plate, chuck, mandrel, boring bar* and *steady rest*. There are other attachments, as taper attachment, center-grinding attachments, etc., which are very useful, but need not be described here.

A face plate is shown at E in Fig. 171. It screws on the end of the main spindle in place of the small face-plate F. Work which cannot be suspended between centers is clamped by means of bolts and iron clips to the face plate.

322. The Lathe Chuck.—Oftentimes work can neither be suspended between centers nor bolted to the face plate. In this case it is held by a chuck, a type of which is shown in Fig. 176. The four jaws (one of which is marked B) may be adjusted in a radial direction by a wrench on one of the nuts C. This nut is the end of a radial screw. The jaws grip the work by clamping down on it or by pressing out against the inside of hollow work of large

diameter. The jaws may be turned end for end to secure work in the two ways just designated.

Chucks have usually three jaws or four jaws, and they are classed as *independent* or *universal.* The jaws of an independent chuck are moved separately by the wrench, while the jaws of the

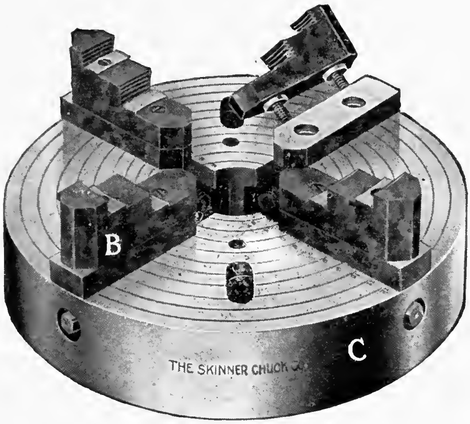


FIG. 176.—Lathe Chuck.

universal chuck have their controlling screws so connected by an internal mechanism as to make then move outward or inward together. Many chucks are made to be changed by a clamp and screw from universal to independent and vice versa. Chuck jaws may be fitted to slotted face plates.

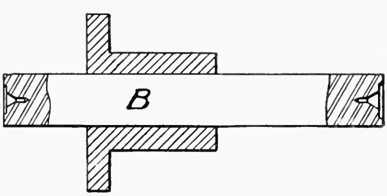


FIG. 177.—Work Mounted on Lathe Mandrel.

323. Lathe Mandrels.—There are many pieces of lathe work which are pierced with a cylindrical hole and which can be mounted on a bar suspended between lathe centers. Fig. 177 shows an arrangement of this kind. The bar *B* is called a *mandrel.* It

has a very slight taper and must fit the work very closely, in fact it is driven into the work by means of a copper maul. Such an arrangement enables both sides of the work to be readily machined. When the work is finished, the mandrel is driven out.

Mandrels are so frequently used in the machine shop, and they must fit the work so neatly that several forms of expanding mandrels have been devised so that one mandrel may suffice for holes varying within a range of about 5 per cent in diameter. Fig. 178 shows a useful type of expanding mandrel which may easily be made in the shop. It consists of a sleeve or bushing *B* and a mandrel *M*. The mandrel is usually about 8 or 10 inches long, centered for suspending between the lathe centers, threaded at one

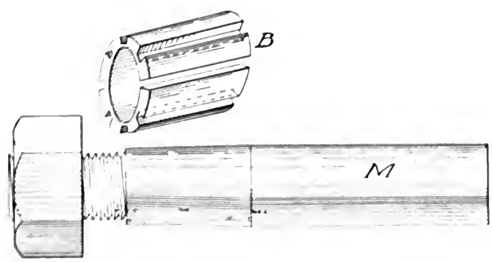


FIG. 178.—Expanding Mandrel.

end for a nut, and tapered for a distance of 3 or 4 inches from the threaded end so that the largest diameter of the tapered part is about 5 per cent more than the smallest diameter. The bushing is reamed inside to the taper of the mandrel, is turned cylindrical outside, has a number of slits cut along its outer surface nearly through the metal, and has one slit cut entirely through. The bushing is slipped, large end first, over the threaded end of the mandrel and is pushed along by aid of the nut until the taper expands it out firmly against the work it is intended to fit.

324. The Boring Bar.—For boring out hollow cylindrical work on the lathe, it is usually secured to the face plate as shown in Fig. 179. If the work does not extend more than 6 or 8 inches from the face plate, it may be bored by the inside boring tool.

For longer work, a bar B is suspended between lathe centers. This bar carries a cutter head C to which is clamped two or more cutting tools as shown. The cutter head is fed along the bar by the handle H, which is pushed by the travel of the lathe carriage.

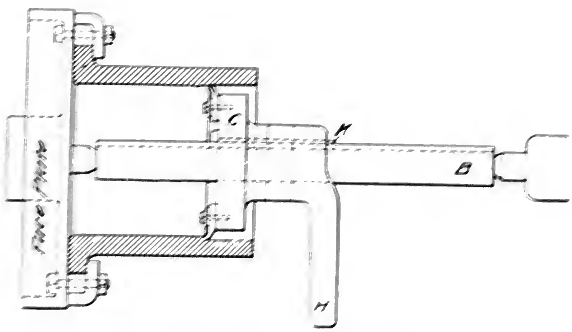


FIG. 179.—Boring Bar.

The key K, traveling in a slot in the bar, keeps the cutter head from revolving.

Another form of boring bar is shown in Fig. 180. The tool slide is removed from the lathe and the cylindrical work is secured on the lathe carriage. The rigid bar, carrying the steel cutter A, is suspended between centers, and as the bar revolves, the work is

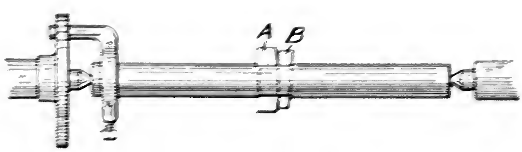


FIG. 180.—Boring Bar.

moved slowly along by the carriage. The pin B keeps the cutter firmly in place.

There are several other types of the boring bar, but boring is a work not usually done on a lathe except in a shop of limited equipment.

325. The Steady Rest.—When a long piece of work is suspended between lathe centers it will sag more or less. Also very heavy work is too heavy for safe support by the lathe centers and additional support must be provided. To prevent sagging and provide increased support for work, a steady rest, as shown in Fig. 181, is used. The principle of this may be provided in simpler form, such as blocking up under the work and making a bearing on wood, or metal kept lubricated.

The steady rest here shown is clamped on the bed of the lathe by the yoke and bolt at the bottom, and the three sliding pieces are

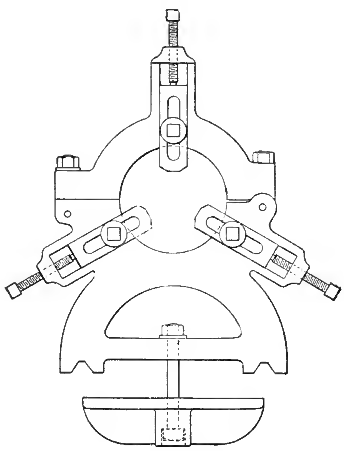


FIG. 181.—Steady Rest.

adjusted by the long screws to support the work at three different points. When work is to be removed from the lathe, the upper part of the steady rest may be opened on its hinge.

326. Centering Work for the Lathe.—Lathe centers must be accurately pointed to an angle of 60°. They must be kept sharp-pointed, smooth, and absolutely free from grit or metal chips.

A bar to be suspended in the lathe must be centered as shown in Fig. 177. The center of each of the round ends of the bar is located by means of dividers or otherwise, marked with a center punch, drilled to a depth of about half an inch or more, and countersunk to fit the taper of the lathe center. The end may be

recessed to insure protection to the countersunk edge. It is highly essential that this center be kept free from grit or chips, burrs of metal, and it must be well oiled.

327. Cutting of Screw Threads.—A screw thread is a helical groove cut on an internal or an external cylindrical surface. The cutting of threads is best and cheapest done by machine. Bolts and nuts are usually cut by dies and taps held in machines for that kind of work exclusively. The lathe and the milling machine are employed to cut threads which must be exact in form.

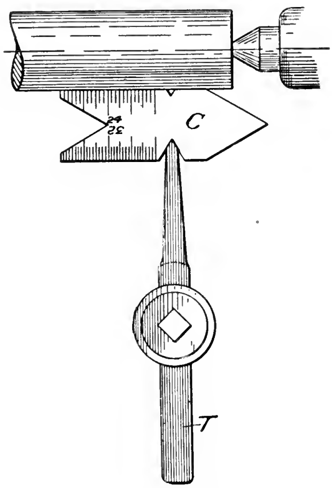


FIG. 182.

The method of cutting a thread in the lathe is as follows: The piece to be threaded is centered and suspended between the lathe centers as shown in Fig. 182. A center gage C is placed against the work for adjusting the threading tool T on the lathe carriage. The notches in the center gage are angles of 60° and are so cut that a line bisecting the angle is perpendicular or parallel, as the case may be, to the two graduated edges of the gage. The cutting end of the threading tool has been ground to a 60° point, as tested by the gage notch, and the adjusting of the tool as shown insures the symmetry of the thread surfaces.

Change wheels are placed on the spindles and on the leading screw at the end of the lathe to make the requisite combination for moving the lathe carriage a definite distance along the bed for each revolution of the work. When the machinist sets the lathe in motion and adjusts the tool point against the work, a groove is cut along the surface of the cylinder and is gradually cut deeper by a number of traverses of the tool until the required depth is attained.

When the tool reaches the end of each cut, it is quickly drawn away, the lathe is reversed to carry the tool back to the starting point, and is again reversed to begin a new cut.

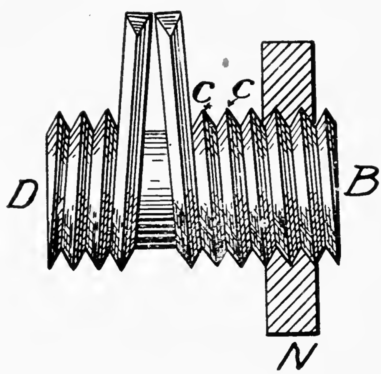


FIG. 183.

328. Forms of Threads. Definitions.—A screw thread may be conceived as formed on a cylinder by winding thereon a piece of triangular wire, as shown in Fig. 183. *N* is a nut, threaded inside to turn on the screw.

If the wire is wound as shown on the end *B*, the thread is *right handed*, if wound in the reverse direction, as on the end *D*, the thread is *left handed*. A right-handed thread is one on which a nut is screwed by turning the nut in the direction of the hands of a watch when the bolt end is pointed toward the operator.

The distance between two adjacent ridges of the thread, as *CC*, is the *pitch* of the screw.

If two triangular wires (of the same size) are wound side by side on the cylinder the thread is a *double thread*. The *pitch* re-

mains the same, but a nut turned one turn on the double thread will advance twice the pitch. The distance which the nut advances in one turn is called the *lead* of a screw, and it will be seen that in this case the *lead* is twice the *pitch*.

The *form* of a thread is the profile it shows in a section made by a plane passing through the axis of the cylinder on which the threads are cut. The form most used is the *V thread,* and other

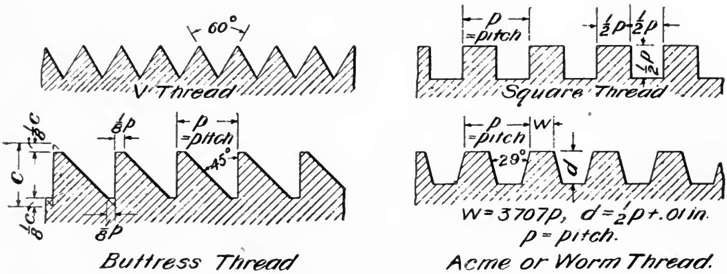


FIG. 184.—Forms of Threads.

forms used for special purposes are the *square thread,* the *Acme or worm thread,* and the *buttress or trapezoidal thread.* These forms are shown in Fig. 184.

329. Standard Threads.—The unlimited forms of threads which may be used has brought about efforts to standardize the *form* and *pitch* of the V thread. The efforts have resulted in the U. S.

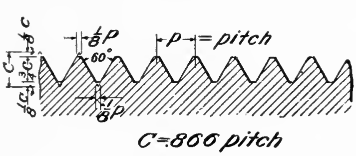


FIG. 185.

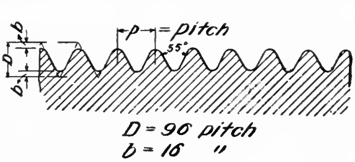


FIG. 186.

standard for the United States, the Whitworth standard for England, and the metric or international standard for Continental Europe.

The form of the U. S. standard is shown in Fig. 185.

The form of the Whitworth standard is shown in Fig. 186.

The pitch of threads is standardized by designating a definite pitch for threads cut on a cylinder of specified diameter; *i. e.*, a

bolt ½-inch diameter has 13 threads per inch, and a bolt of 1-inch diameter has 8 threads per inch by the U. S. standard.

Small threads may be cut on the lathe by the hand chasers shown in Fig. 187, though these are more conveniently used for cutting out to a greater depth a thread which was not cut deep enough.

Thread gages for measuring the pitch of threads are among the small tools for machine shop use.

330. Drilling Machines.—The cutting of cylindrical holes of greater or less size in metals is a very varied requirement in machine-shop practice and many methods are employed for accomplishing this work, depending upon the diameter and length of the hole. Small holes are drilled on the drilling machine, very long holes, as in gun barrels or propeller shafting, are drilled in the boring lathe, and cylindrical holes of large diameter, as in a steam cylinder, are bored on the boring mill. Usually a hole is cast in a casting to reduce to a minimum the work of boring, and in a less degree forgings are made hollow, when so required, for the same purpose. Generally the term *drilling* is applied to the cutting of small holes by a drill, and *boring* is applied to the cutting of larger holes which may or may not have been previously made in casting or forgings.

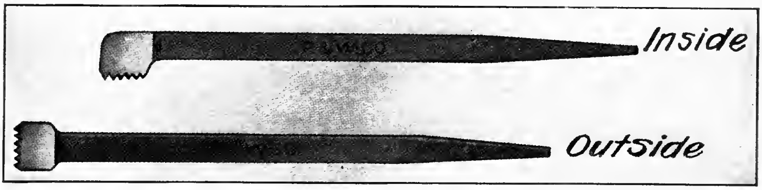


FIG. 187.—Hand Chasers.

There are many different styles of drilling machines. The principal styles among these are (1) the vertical drill; (2) the radial drill; (3) the gang drill, and (4) the multiple spindle drill. There are many sizes of each of these styles designed for particular kinds of work.

331. The Vertical Drill.—Fig. 188 shows a vertical drilling machine of a type much used. The drill is carried in a socket in the lower end of the vertical spindle *VV*. The spindle is made to

revolve by a belt on the cones *CC*, and is fed gradually downward either by the power-feed mechanism driven by a belt over the small cones *SS*, or by the hand lever *L* which may be swung down horizontally for convenient handling. Both power and hand feeds may be readily thrown out of gear when the spindle is to be

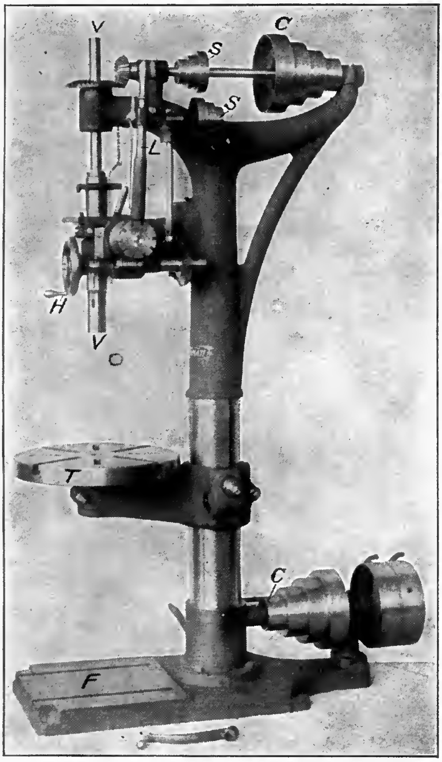


FIG. 188.—Vertical Drill.

quickly raised or lowered by the hand wheel *H*. The spindle moves up and down in a vertical direction.

Work to be drilled rests on the table *T*, or may rest on the base *F*. The faces of both the table and the base are horizontal, hence are always perpendicular to the direction of travel of the drill. The table may be adjusted vertically or swung horizontally as desired.

A shop usually has a small vertical drill fed only by hand and used for drilling holes of 1/4-inch diameter or less. This is known as a *sensitive drill.*

Gang drills and *multiple spindle drills* have several spindles and drill several holes at the same time.

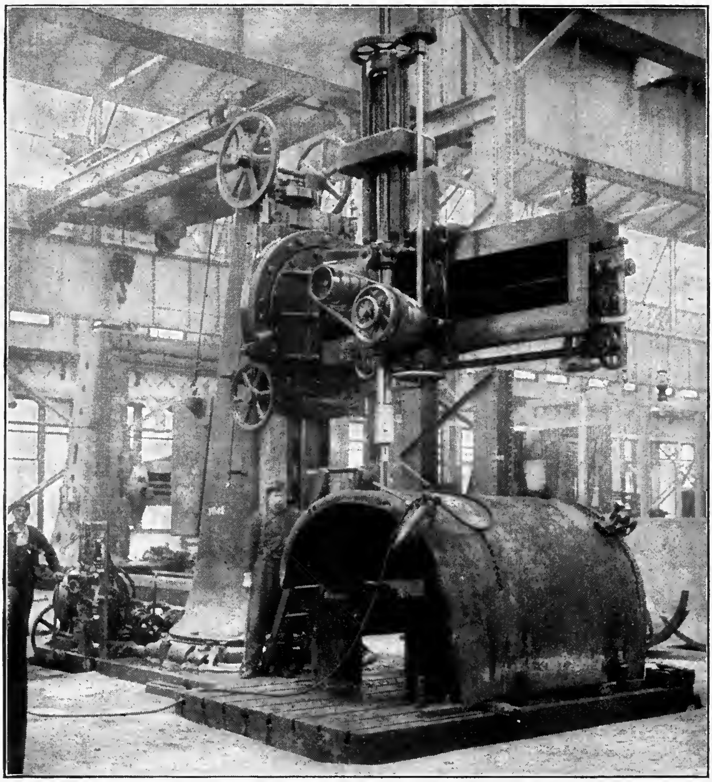


FIG. 189.—Full-Universal Radial Drill.

332. The Radial Drill.—The changing of position of work on a machine consumes time which may add considerably to the expense of large work. The radial drill is so designed that when a piece of work is secured to the drill table, which is placed on a solid foundation for holding very heavy work, the drill spindle may be placed over any part of the work without moving the latter.

There are three classes of radial drills, viz., (1) the *plain* radial drill, in which the drill spindle is always vertical, but may not be swung over any point of the work; (2) the *half-universal* drill in which the spindle may be swung over any point of the work and in addition may swing in one plane at any angle to the vertical up

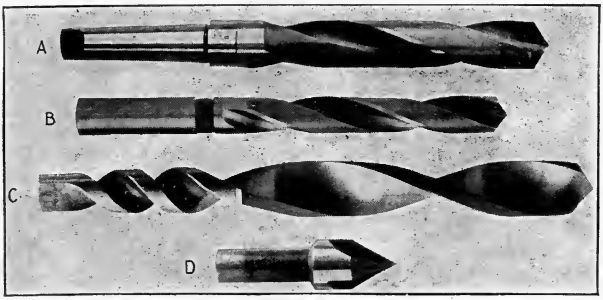


FIG. 190.

to complete reversal of the direction of the drill, and (3) the *full-universal* drill in which the spindle may be swung in any plane at any angle to the vertical. Fig. 189 shows a universal radial drill the drill spindle of which may be moved to any position within the reach of the machine and placed at any angle desired.

333. Drills and Attachments for Drilling Machines.—Fig. 190 shows three twist drills and a countersink which are much used

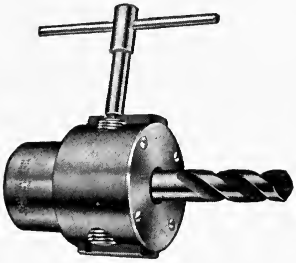


FIG. 191.—Drill Chuck.

with drilling machines. Drill *C* is made of a twisted bar of high-speed steel. Drills *A* and *C* have *taper shanks.* They are placed in a taper socket and the socket is placed in the end of the drill spindle. Drill *B* and the countersink have *straight shanks.* They are held in a small chuck shown in Fig. 191. Small drills have

straight shanks. The countersink is used for reaming the end of a hole to the shape of a lathe center.

A vise, of which Fig. 193 is one type, is necessary for holding small work accurately on the drill table.

When the drilling of holes in duplicate pieces of work is repeated many times, a *jig* is made with the holes drilled through it in correct position and this is used as a guide for drilling by placing it over the work and thereby avoiding the necessity of marking the holes on each piece. Work of this kind is quickest done on a multiple spindle drill. Jigs in simplest form are made from plates of cast iron or rolled steel. Many forms of jigs, however, are very elaborate, consisting of cast-iron boxes with guide holes drilled through the sides at the desired angles and protected by bushings. A piece of work to be drilled is placed in one of these box jigs and secured in a particular position to insure drilling similar holes alike in every piece.

334. The Planer.—This machine is used to cut plane surfaces or straight grooves. Fig. 192 shows a type of planer much used. Work is secured usually by bolts and clips to the heavy table *T*, the surface of which is level. This table is made to move, by mechanism under the machine, back and forth along two level V-shaped grooves *B* in the planer bed. The distance of travel of the table is governed by two adjustable stops *EE* which strike a lug of the reversing mechanism on the side of the planer bed and cause the two driving belts to shift on the pulleys *GG*. One of these belts is open and the other is crossed to drive the pulley in opposite directions. The middle wheel runs idly and merely facilitates the shifting of the belts.

All that part of the machine above the table is designed for holding the tool rigidly and for controlling its horizontal and vertical adjustment. The *housings HH* carry the *cross-rail C* which may be raised or lowered by the hand mechanism above the machine. The *head D* slides horizontally along the cross rail, and its parts are arranged for raising or lowering the tool, and for setting to tool at an angle to make cuts along the sides of a piece of work.

The tool is clamped by four bolts to the apron *A*, and it makes a cut only when the table travels to the right in the view here

shown. When the work travels back to the left, a horizontal bolt *J* which hinges the upper edge of the apron *A* allows the tool to swing out of the way as it drags over the work. The tool may be gradually fed horizontally across the table or may be fed vertically. The feeding mechanism is marked *KLPRS*. This mechanism moves the tool after it has finished its cut and when the machine is reversing. When a series cuts is finished across a piece of work, the tool point is lowered slightly by the handle *N* for another series.

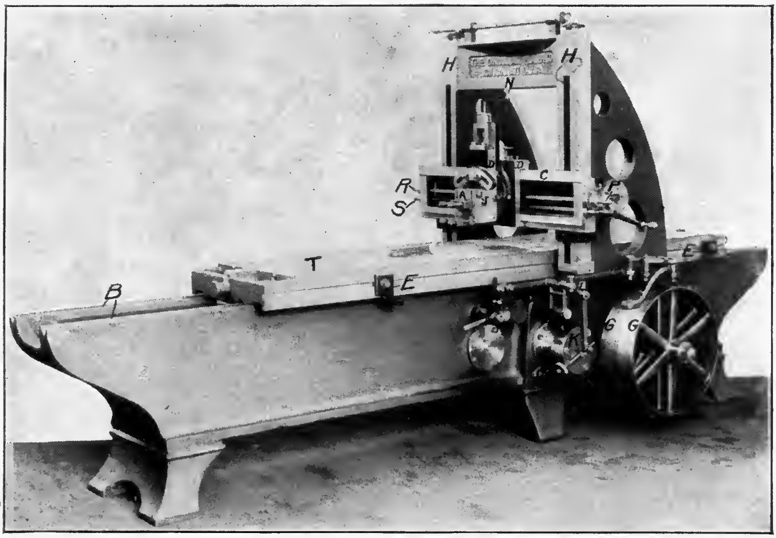


FIG. 192.—Planer.

The driving mechanism of the planer table is designed to give the table a quicker motion for the return than for the cutting stroke. This is known as the *quick return motion.*

335. Types of the Planer.—For very heavy work of considerable bulk, an *open-sided* planer is used. This is somewhat similar to the planer just described, except that one of the housings is omitted.

Another type of planer designed for planing off the end of a large forging, too long to rest cross-wise of the planer bed, is the

rotary planer. The work is secured to a fixed base plate, and the end is presented to the face of a heavy revolving disc which carries many cutting tools. As the disc revolves, the tools cut the end of the work, which is fed in a direction parallel to the face of the disc.

336. Planer Tools.—As in the case of lathe tools, these are made of rectangular steel bar material, forged, hardened, and ground to shape. The planer has fewer regular tools than the lathe. There is no threading tool for the planer, but the round nose and side tools are very similar for lathe and planer. A square-nose finishing tool is much used with the planer.

337. The Planer Chuck and Planer Jack.—The chuck or vise shown in Fig. 193 is very useful for planer and shaper work. It is

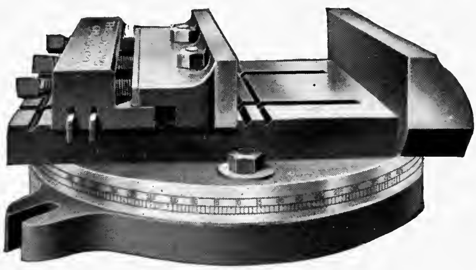


FIG. 193.—Planer Chuck.

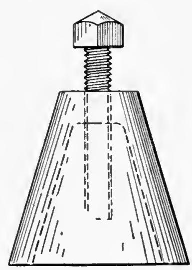


FIG. 194.—Planer Jack.

bolted to the table and used to hold small work in exact position for accurate cutting.

In the careful adjusting of heavy work on the planer table to the position desired for planing, small jacks such as shown in Fig. 194 are used. These are of various heights, from about $1\frac{1}{2}$ to 6 inches or more. They may be left under the work, but it is best to replace them with wedges of wood or iron, on which the work rests.

338. The Planing of Propeller Blades.—The driving surface of a propeller blade is made up of straight line elements radiating from the axis of the propeller. This fact enables a true and smooth surface to be machined on the blade by means of the planer. The driving surface of the blade is generated by a straight line moving at a uniform rate along the axis of the propeller and at the same time revolving about this axis at a uniform angular rate.

A device has been perfected which rests on the planer table and holds a single blade in such position that an element of the blade is parallel to the direction of motion of the table. This device has a feeding arrangement which gives the blade such a combined motion of translation and revolution that each of its elements in succession is brought into a position which the tool will follow as the table moves.

In the foundry, a propeller-blade mould is swept up in loam by a sweep, the edge of which is raised and revolved at the same time to generate the driving surface of the blade.

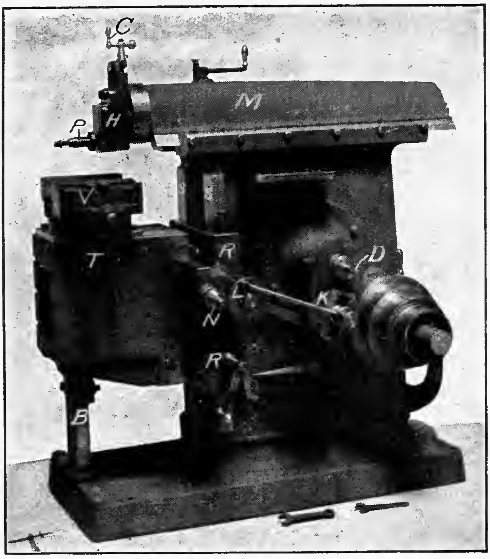


FIG. 195.—Shaper.

339. The Shaper.—This is virtually a planer for planing small work. It is not designed like the planer, however, and the essential difference is that the work table remains stationary, except for the feeding motion, and the tool is moved back and forth over the work. The shaper is a quicker-moving machine than the planer. It cuts in but one direction of its stroke.

Fig. 195 shows a type of small shaper much used. A feature of all shapers is the quick-return motion, as mentioned for the planer.

The Whitworth quick-return motion is much used in shaper mechanism.

Work is clamped in the vise *V* which is bolted to the table *T*. The table is carried by the cross-rail *R* which may be raised or lowered by hand mechanism along its slide *S* at the front of the column of the machine. An adjustable support *B* assists to hold the table rigidly.

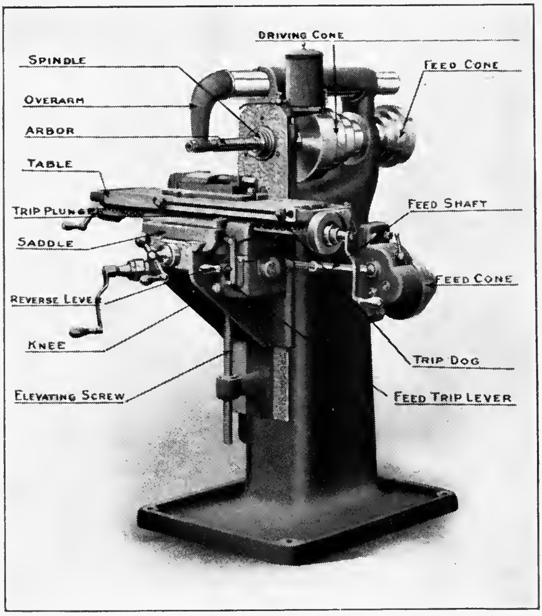


Fig. 196.—Plain Milling Machine.

The tool, which is not unlike a lathe tool in form, is clamped in the tool post *P* which is carried by an apron on the head *H*. This head is carried by the ram *M* which is made to slide back and forth in its guides on the top of the machine. The vertical position of the tool is adjusted by the screw handle *C*. The length of travel of the ram is adjusted to suit the work by a hand crank on the spindle *D*, and the range of its travel, *i. e.*, the limits of the ends of its stroke, is governed by the crank above the ram.

The machine is driven by means of a belt on one of the cone wheels. As the ram moves back and forth, the table is gradually fed at the end of each stroke along the cross rail by the mechanism *KLN* until the work is carried entirely across the range of travel of the tool. The tool is then slightly lowered by the screw handle for a new cut, and the table is fed back in the opposite direction.

The machine is so built that the ram and table move horizontally, one at right angles to the other, and the cross rail raises or lowers vertically.

For holding small flat work of steel or iron quickly and readily, a small electro-magnetic chuck has been designed for use with the shaper. It is bolted to the table or clamped in the vise and is supplied with direct current for the magnets.

340. The Milling Machine.—This machine is shown in simple form in Fig. 196. Milling machines are used for both plain and intricate cutting of great variety. They are adopted to that kind of cutting which is of particular or peculiar contour, which must be in particular relative position to other cutting on a piece of work, and which must be accurate to a high degree.

Milling machines are employed mostly on small work, yet some machines are built for large and heavy work.

The teeth of plain and helical gear wheels, the spiral grooves in a twist drill, the longitudinal grooves in taps and in many forms of milling-machine cutters, slots and key-ways in shafts, screw threads of long pitch, and hexagon nuts or other prismatic work may be mentioned as examples of milling-machine cutting. A milling machine may be used for such cutting as is done on a small lathe, shaper, drill, boring machine and slotting machine, or for any combination of the kinds of cutting done by any of these machines. With the several attachments now designed for the modern milling machine, it can do, within the limits of size of its work-table, the work of any other machine tool in the shop, and even more.

341. Description of the Milling Machine.—Work is held in a vise or other attachment which is bolted to the slots of the *table* (Fig. 196). Wheel-shaped cutters placed on the *arbor* are made to revolve by means of the main *spindle* which is hollow, and on

which is keyed the *driving cone.* The outer end of the arbor is supported by the adjustable *over-arm.* The cones are driven by a belt from similar cones overhead.

After work is secured on the machine and cutters are placed on the arbor, the table is adjusted by hand mechanism to bring the work in range of the cutters. The table may be raised or lowered by the *elevating screw* which controls the vertical-sliding *knee,* and it may be adjusted horizontally toward or from the body of the machine by moving the *saddle* which, in the plain machine, slides back and forth in but one horizontal direction on the knee. The table, the saddle and the knee are adjusted by means of the four cranks shown.

When the machine is in operation, with the work adjusted for cutting, the table is fed horizontally along the saddle in either direction perpendicular to the axis of the arbor, by means of the *feed shaft* and its mechanism. The *reverse lever* determines the direction of travel of the table, and the *trip dogs* are adjusted to stop the table within certain limits of travel as they come into contact with the *trip plunger.* The *feed-trip lever* is used to stop the feed instantly by hand. The whole feed mechanism is driven by a belt on the *feed cones.*

Some forms of cutters, which reach into grooves or slots in a piece of work, have their own shanks which fit into a socket or collet similar to a drill shank. This collet fits into the end of the spindle. When these cutters are used, neither the arbor nor the over-arm are used.

342. The Universal Milling Machine.—The machine in Fig. 196 is known as a *plain* milling machine because its table cannot turn on the saddle. The machine in Fig. 197 is a *universal* milling machine, as its saddle is made in two parts, divided horizontally at *H* and so adjusted that the upper part may revolve on a vertical spindle on the lower part, allowing the table to be turned to a considerable angle from its position as shown in the plain machine. The junction of the two parts of the saddle is marked by a graduated circle so that the angle through which the table is moved can be readily measured.

The parts of the machine (similarly named to those of the plain machine) are as follows:

S. Spindle.
C. Driving cone.
F. Back gear.
B. Elevating screw.
H. Saddle.
TT. Work table.

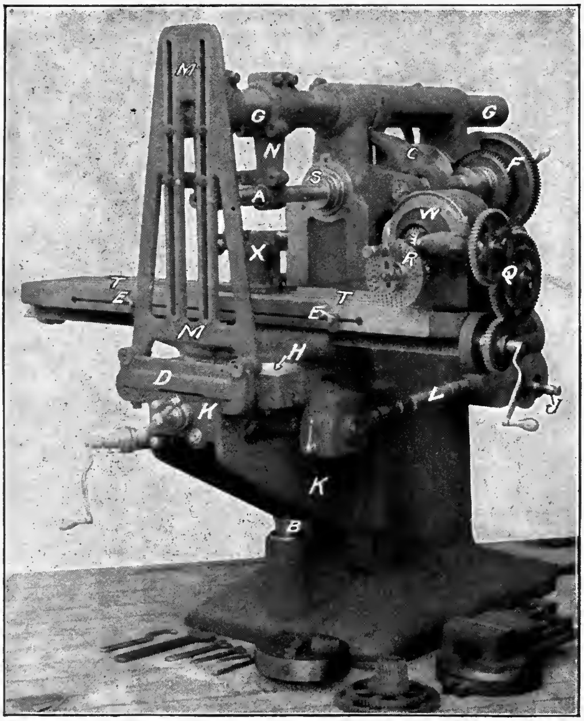


FIG. 197.—Universal Milling Machine.

A. Arbor.
N. Arbor support.
GG. Over-arm.
MM. Over-arm brace.
D. Brace clamp.
KK. Knee.
EE. Trip dogs.
L. Feed shaft.
J. Reverse lever.
W. Dividing head.
X. Foot stock.

The dividing head and foot stock correspond to the head and tail stocks of a lathe. The dividing head is used in cutting gear wheels, sides of prisms, and similar work which must be divided into an exact number of parts around its periphery, as shown in

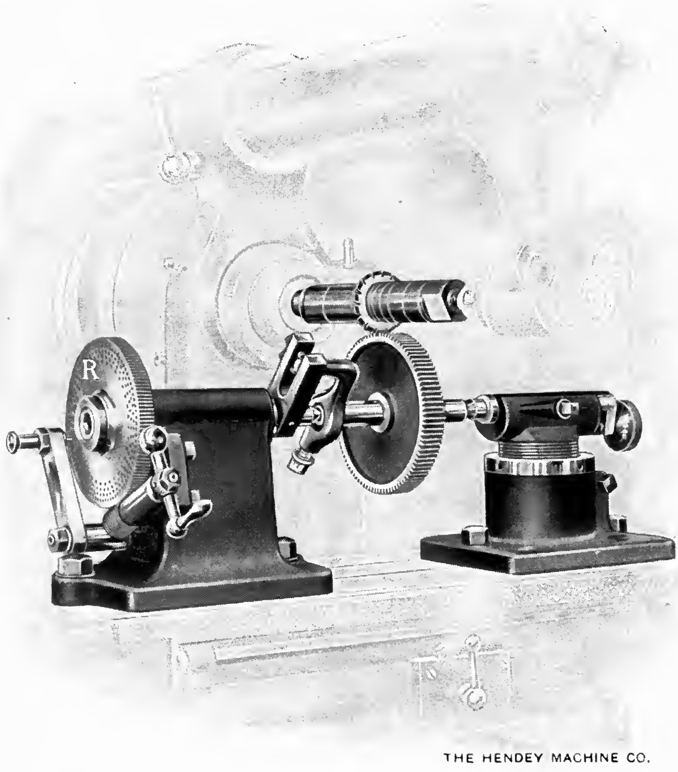


FIG. 198.—Example of Milling-Machine Cutting.

Fig. 198. Divisions are regulated by the dividing wheel *R*. When work suspended on the centers of the dividing head and the foot stock must be given a motion of revolution as part of the operation of milling it, the gear wheels *Q* (Fig. 197) are connected to the feeding mechanism of the machine. For cutting spiral grooves and coarse threads, the work is revolved on these centers and at

the same time is given a motion of translation by the movement of the table.

343. Milling-Machine Cutters and Arbors.—Fig. 199 shows a group of cutters, arbors and collets.

Cutters are made of high-speed steel for roughing cuts and of carbon steel for lighter or finishing cuts. After a cutter is hardened for cutting it is ground to exact shape in a special machine made for accurate grinding. In this way all the teeth of a cutter are made to cut in the same path.

344. Milling-Machine Attachments.—The usual milling-machine attachments are the vise and the dividing head, both for holding work.

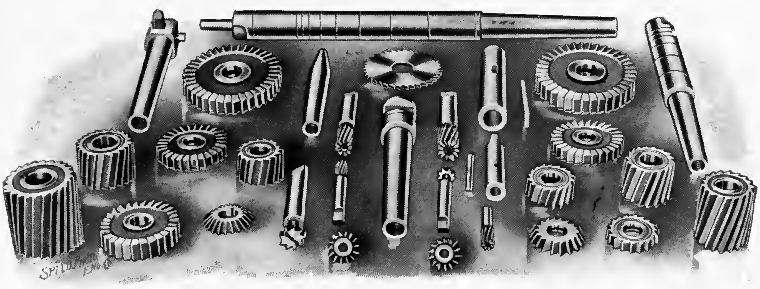


FIG. 199.—Milling-Machine Cutters, Arbors and Collets.

There are, beside these, a number of attachments which are bolted to the face of the column over the end of the main spindle and connected to the spindle for changing the direction of motion of the spindle or for otherwise modifying this motion to do many kinds of work. Milling-machine attachments include those for drilling, slotting, beveled cutting, vertical milling and other purposes.

345. The Boring Machine.—There are two general types of this machine, both of which were designed primarily for boring hollow cylinders too large for boring on the lathe. The two types of the boring machine, each of which has several varieties, are (1) the horizontal boring and drilling machine, and (2) the vertical boring and turning mill. These machines have been developed, as their names indicate, to do other work besides boring.

The boring of large gun tubes, small gun barrels, and long shafts, which may be forged either hollow or solid, is done on a special type of lathe, and cannot be done on the boring machines here mentioned.

346. The Horizontal Boring and Drilling Machine.—Fig. 200 shows a representative type of this machine. A cylinder to be bored is so clamped on the upper cross-table *T*, and the table is so adjusted, that the cylinder axis and that of the spindle *SS* are coincident. This adjustment is made by raising or lowering the main table *MM* by means of the lever *B* which works the large

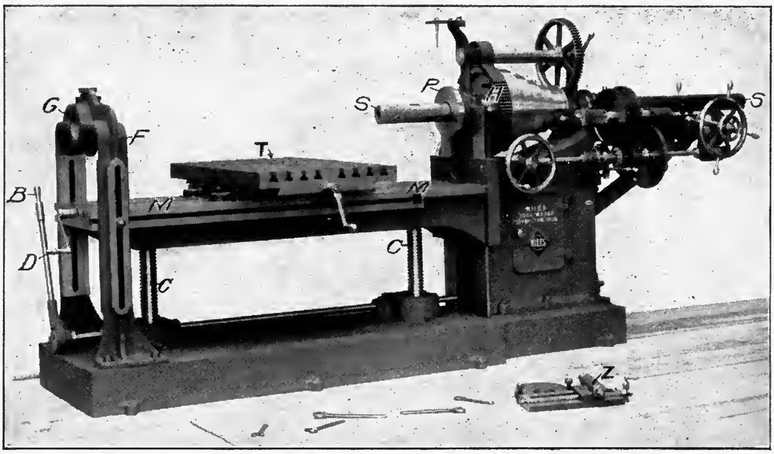


FIG. 200.—Horizontal Boring and Drilling Machine.

screws *CC*, and by sliding the table *T* across the main table. The handle *D* moves the table *T* along the main table. The faces of the tables *T* and *M* always remain horizontal, and the tables are not moved while the boring is in progress. The main table is supported at the left by the large yoke *F*.

After the cylinder is adjusted, a boring bar with suitable cutters is passed through the cylinder for boring. One end of the bar fits into the end of the main spindle *S*, and the other end is supported in a bushing in the hole *G*. The bar with its cutters is made to revolve by means of the wheel *H*, which is driven by the belt cones and back gear as on the lathe. The bar and spindle are

advanced slowly, while they revolve, by the feeding mechanism seen at the right of the machine. This mechanism is fitted to give the cutter different speeds of advancement in either direction of the spindle's length, and the hand wheels are fitted to change the position of the spindle quickly when the machine is not in operation.

This machine has the advantage of being able to bore several parallel holes in a casting without having to re-adjust the casting on the table, as the tables themselves provide for moving the several holes into position for the cutters.

Some machines have an upper table which revolves around a vertical axis on the lower table, thus fitting them for boring a series of holes with horizontal axes at given angles one to another.

The ends of a cylinder may be faced off by means of a tool secured to the attachment *Z*. This attachment is bolted to the face-plate *P* and the tool is fed to cut at a gradually increasing distance from the spindle axis.

A drill may be held in the end of the main spindle for drilling holes as on the drilling machine.

347. The Vertical Boring and Turning Mill.—This machine, shown in Fig. 201, is used for boring large steam cylinders, gun-hoop forgings, locomotive drive-wheel tires, fly wheels, and similar large work. This work may also be faced or turned on the ends, just as can be done on the face plate of a lathe.

Work to be turned or bored is clamped on the heavy revolving table *T*, which revolves on a vertical axis. This table is virtually a face plate, as on the lathe. The housings *HH* of the machine, and all the fittings they carry, are for holding rigidly and governing the movements of the cutting tools. A tool is clamped in each of the holders *BB* on the tool bars *CC*, and both tools may be fed independently in a vertical, horizontal, or slightly inclined direction as desired. Either tool may cut inside, outside or on the upper end of a piece of work.

The tool bars may be inclined about 30° on the swivel head *DD*, and these heads are readily adjusted along the cross rail *RR*. The cross rail is readily adjusted vertically along the faces of the housings. The tool bars are raised or lowered by the hand wheels on the swivel heads when adjusting them for cutting operations.

They are made very heavy for rigidity and their weight is counterbalanced by a heavy weight on the ends of the chain K.

The mechanism on top of the machine adjusts the various parts preparatory to operating the machine, and the feed mechanism at

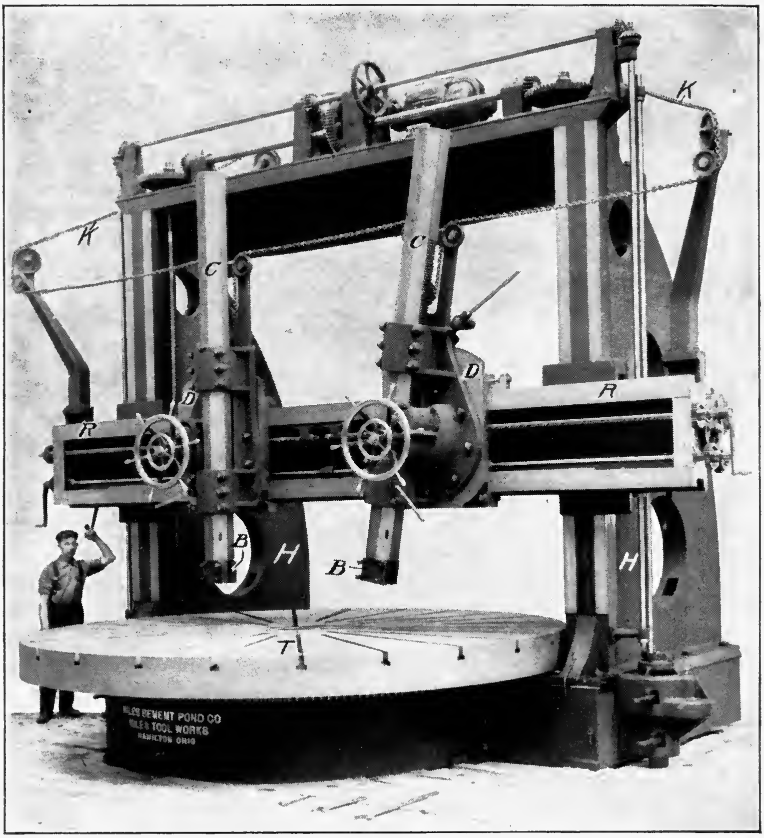


FIG. 201.—Vertical Boring and Turning Mill.

the right controls the feeding of the tools while they are cutting. The machine is driven by a motor not in view.

Some designs of this machine are fitted with equipment and attachments, not here shown, for many varieties of machining, increasing its usefulness particularly in saving time required to shift a heavy cylinder to another machine and adjust it thereon.

348. The Slotting Machine.—A type of this machine is shown in Fig. 202. This is known as the crank-driven type to distinguish it from the heavier gear-driven type.

The slotting-machine movements resemble very much those of the shaper. The machine is employed particularly for slotting key ways in the hubs of wheels, and is found useful for much

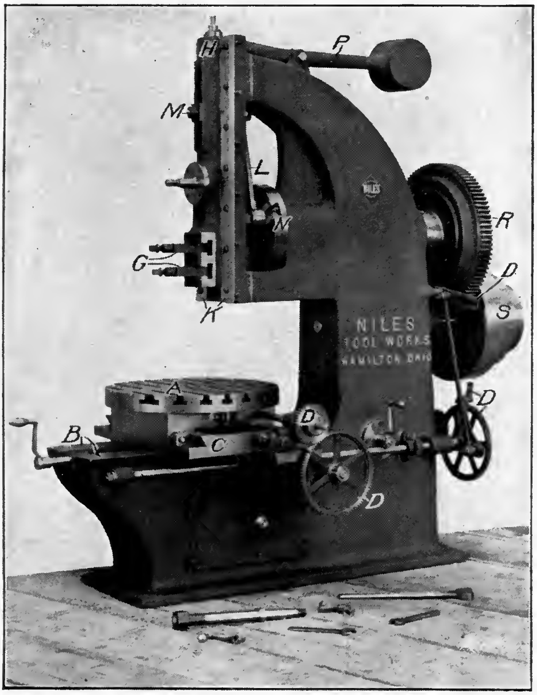


FIG. 202.—Slotting Machine.

other slotting of various kinds. Work is clamped on the horizontal table A which may be adjusted by giving it (1) a circular motion; (2) by moving it horizontally along the slides B, or (3) by moving it horizontally along the saddle C at right angles to the motion of (2). These motions may be imparted to the table slowly by the feed mechanism D, which changes the position of the work gradually during the course of the operation of slotting.

The cutting tool moves up and down in a fixed vertical line perpendicular to the face of the table. It is clamped firmly in the yokes *G* at the end of the ram *H* which works in the guides *KK*. The ram is operated by the connecting rod *L*, the upper end of which swings on the bolt *M*, and the lower end of which is held on a crank pin which may be readily adjusted along the dovetail slot in the disc *N* to give the tool a greater or less length of movement. The weight of the ram is counterbalanced by the weighted lever *P*. The disc *N* is on the end of the main spindle which is driven with a quick return motion by the large wheel *R* geared to the driving cones *S*.

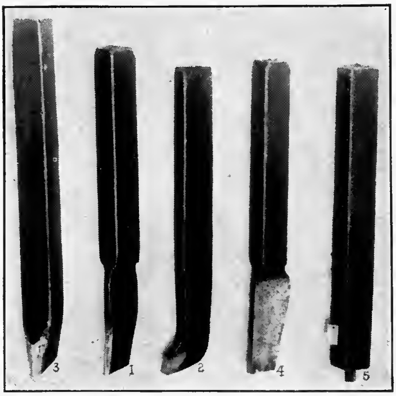


FIG. 203.—Tools for the Slotting Machine.

The path along which the point of the tool moves may be raised or lowered by raising or lowering the ram in reference to the nut at *M*.

349. Tools for the Slotting Machine.—Fig. 203 shows a few slotting-machine tools for general use, although many forms may be made for special uses. They are designated as follows:

(1-2) Roughing tools.

(3) Finishing and filleting tool.

(4) Key way and cutting-off tool.

(5) Holder for tool points of high-speed steel.

These tools are made to cut as they move downward in the direction of their length. Other tools may be shaped to be clamped on the ram so that they cut in a direction perpendicular to their length.

350. Pipe Cutting and Threading Machines.—The cutting and threading of steam and gas pipes is done to a considerable extent by hand appliances, but the best results are obtained by a machine which cuts and threads a pipe while holding it rigidly in exact position. These machines are hand or power driven, or may be driven by hand and power.

Pipe cutting and threading may be done accurately in a lathe, provided the pipe is not too long for the lathe. Pipe threading by

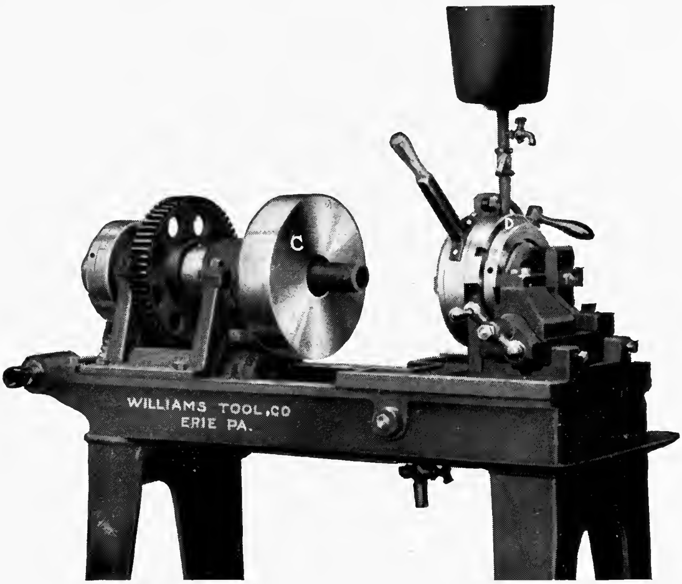


FIG. 204.—Pipe-Cutting and Threading Machine.

means of hand appliances does not give satisfactory results when many short lengths of pipe are to be joined in a more or less intricate system, because hand appliances cannot usually cut a thread so that a pipe will turn on its axis while screwing it into place.

Fig. 204 shows a small machine which grips a piece of pipe in a chuck *C* and revolves it in contact with a cutting tool at the right of the machine. The die head *D* also carries the adjustable thread chasers which thread the end of the pipe.

351. Tool-Sharpening Machines.—The grindstone is still employed for sharpening metal-cutting tools, but it has been in a great measure displaced by emery or carborundum grinding wheels.

Many types of tool-grinding machines are now common among machine-shop equipment. One of the smallest consists of an encased electric motor whose shaft carries a small grinding wheel on each end, with adjustable rests at the side and edge of each wheel for steadying work held in the hand. This small machine is usually mounted on a bench.

Another type much used is the heavy wheel, motor driven, mounted on a closed base and partly covered by a hood.

A machine shop sometimes has machines other than tool-grinding machines especially designed and built for very accurate circular or flat grinding, but this degree of accuracy is not required in the usual run of machine-shop work.

352. Metal-Cutting Saws.—It is frequently necessary to cut bars, rods, standard rolled shapes, etc., into definite lengths for various needs. This may be done by shearing or by sawing, and the oxy-acetylene flame is now used for metal cutting with remarkable practical success.

The sawing machines gives smooth ends at any desired angle to the axis of the bar sawed without wasting much metal.

The smaller metal-sawing machines consist essentially of a small, straight saw blade held in a tightening frame and dragged back and forth across the work to be sawed. Machines of larger size are equipped with a heavy circular saw between 1/8 and 1/4 inch thick and between 12 and 30 inches in diameter. The saw revolves slowly and is fed gradually into the work which is clamped firmly on the table of the machine.

353. Forcing Presses.—These are used for forcing wheels on spindles or shafts. They vary in size from those requiring hand power applied through screw rods, to those requiring the pressure of a heavy hydraulic cylinder. A heavy hydraulic forcing press is used to force locomotive drive wheels and car wheels on or off their axles, to force electric armatures on the shafts which carry them, and to force wheels and crank discs on engine shafts.

354. Machine-Shop Notes.—Under this paragraph will be given a few notes applying to machine-shop practice in general.

(1) The cutting speed of tools is determined by the heat generated in cutting. When the tool and the work cannot conduct this heat away fast enough to prevent, the tool point becomes heated and is itself ground away. This condition of heating is avoided in many tools like milling cutters, metal saws, rotary planer cutters, etc., where each tooth does not cut continuously. For continuous cutting by one tool point as in the lathe, the high-speed steels are much superior to carbon steel for removing a large quantity of metal, but carbon-steel tools are better for the lighter finishing cuts. Some high-speed steels will cut satisfactorily with the tool point at a red heat.

(2) Oil or soapy water applied to a cutting tool assist in keeping down the temperature, and soapy water gives a smooth bright surface in the finishing cut of iron and steel.

Brass is cut at a rapid speed and is just brittle enough to be given a smooth surface by the cutting tool, while copper is difficult to cut by machining because it is so ductile that chips do not tear away readily.

(3) Work is secured to face plates, chucks, planer and other machine tables by bolts or clamps. Care must be taken that these fastenings do not spring the work so that the machined surfaces will be distorted when the fastenings are removed. It is well to ease up the fastenings of a piece of work just before taking the finishing cut, leaving enough holding pressure to keep the work from slipping.

(4) Large castings which are to be machined to accurate form and dimensions should be allowed to "season" for a few weeks before machining is done, especially if these castings are to contain steam. It has been found that castings undergo a gradual change of shape, detected only by careful measurement, soon after having been cast. This is of particular importance with castings for steam turbines and with steam cylinders. In case a casting is hurriedly needed, as in emergency repairs, it may be rough machined after casting and then heated slowly and evenly, and allowed to cool slowly.

(5) To safeguard the strength of metal, a fillet should always be left at the enclosed angle formed by the junction of two surfaces in different planes, as was mentioned in the chapter on pattern making.

It is frequently necessary to turn a shaft to two diameters as shown in Fig. 205. A straight fillet as at *d,* or better a rounded fillet as at *b,* should always be left at the junction of the larger and the smaller parts of the shaft. Another style of fillet, known as a *hidden* or *blind* fillet may be used where those like *b* or *d* would be in the way, as, for example under a bolt head, as at *k.* Blind fillets are advantageous where the pins and journals of a crank shaft join the webs.

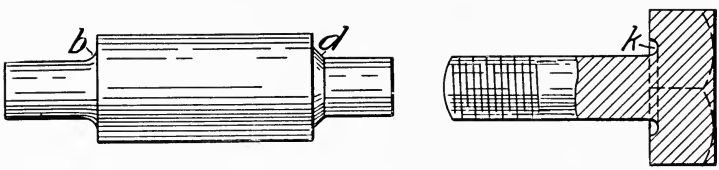


FIG. 205.—Examples of Fillets.

(6) The drilling of holes with large twist drills is increased in speed and accuracy by first drilling a small hole, say ⅛ of an inch, to act as a pilot or guide hole.

To cut a hole accurately round and with the axis in a given direction is not a simple operation, though ordinary bolt or rivet holes do not require any such degree of accuracy. Hole-grinding is accomplished by use of a small, rapidly revolving grinding wheel of less diameter than the hole to be ground.

A round hole may be made square or polygonal by broaching out. This consists of drawing or pushing through the hole, steel pins of such cross sections as will cut out the hole to the shape desired.

(7) Deep-hole boring, as in boring gun tubes, gun barrels and propeller shafts, is done by a long bar which carries a cutter on one end. Either the work or the cutter bar revolves on its axis, and the bar is pressed with sufficient firmness against the work to make the cutter "bite" so long as the rotary movement continues. The cutter bar and cutter must be hollow to keep the work cooled by a circulation of water through this hole. This also

flushes away the chips of metal. The bar is not as large in diameter as the hole bored so that the chips can be washed out. Finishing to the required outside diameter is done after boring. Small gun barrels are held vertically to be bored, to keep the cutter from being drawn to one side of the barrel by gravity.

(8) In machining large shafts or gun tubes made from forged steel ingots, the cutting away of the superfluous metal in the lathe frequently reveals small cracks below the rough surface of the forging. These cracks are caused by unequal cooling of the ingot, and may not be numerous nor large enough to impair seriously the strength of the forging, but each crack revealed must be carefully investigated to determine its extent. It is the practice to stop the lathe when one of these cracks is revealed, and to cut out the crack with a cold chisel. If its depth does not extend below the metal to be machined off the forging, the machining is again resumed.

(9) In machinery designations the terms bearing and journal are often confused. A *bearing* is the support in which a shaft or axle revolves, and a *journal* is that part of the shaft or axle which is in contact with the bearing.

355. Bench Work in the Machine Shop.—Some work in the machine shop, as chipping, filing, scraping and reaming, is done by hand. Cutting threads on small bolts and pipes is frequently done at the bench, although such work is not economical.

The important tools and equipment much used in bench work are as follows, many of which are well known:

(1) Bench vise.	(9) Scrapers.
(2) Hammers.	(10) Surface plates.
(3) Cold chisels.	(11) Hack saw.
(4) Files.	(12) Copper maul.
(5) Reamers.	(13) Abrasive materials.
(6) Taps.	(14) Scriber.
(7) Dies.	(15) Center punch.
(8) Wrenches.	

(a) The vise has jaws hard enough to resist wear, but not brittle enough to chip off when struck with a hammer.

(b) A reamer is used to cut a drilled hole to larger diameter. Reamers are either (1) cylindrical (called straight reamers) for enlarging holes very slightly to exact cylindrical form and given diameter, or (2) tapered for enlarging holes to a considerable degree. The end of a straight reamer must be slightly tapered to allow it to enter the hole to be reamed out. The straight reamer soon wears enough to reduce its diameter and lose its accuracy if used for any except light cutting. *Expansion* reamers have been devised to be sprung out as they wear.

Rose and *shell* reamers are made for use on lathes, drills and milling machines. A rose reamer has teeth on the end for boring out a hole, as well as teeth along the body for finishing to an exact diameter.

A B

Fig. 206.—Cold Chisels.

(c) The hack saw is very handy for sawing metal bars and rods. It consists of a thin, narrow steel saw-blade, very hard, held in a bow frame of steel by which it is kept stretched taut.

(d) The copper maul is used for such work as driving a finished shaft into the hub of a metal wheel. The soft copper saves marring the finished metal surfaces.

356. Cold Chisels.—These are usually made from octagon-bar steel, hardened at the cutting ends. The two forms most used are the *flat* chisel *A*, and the *cape* chisel *B*, shown in Fig. 206. The blade of *B* is much narrower than that of *A*. Other forms, as the half-round and V-cornered, are very useful.

357. Files.—The many kinds of files are classed according to (1) length; (2) form of teeth, and (3) shape of cross section of the body of the file.

The usual forms of teeth are classified as shown in Fig. 207. There are finer-toothed files than the "smooth," the most used of which is the "dead smooth."

In cross-section, the usual shapes are (a) rectangular, including *mill, flat, pillar, square* and *warding;* (b) round or partly round,

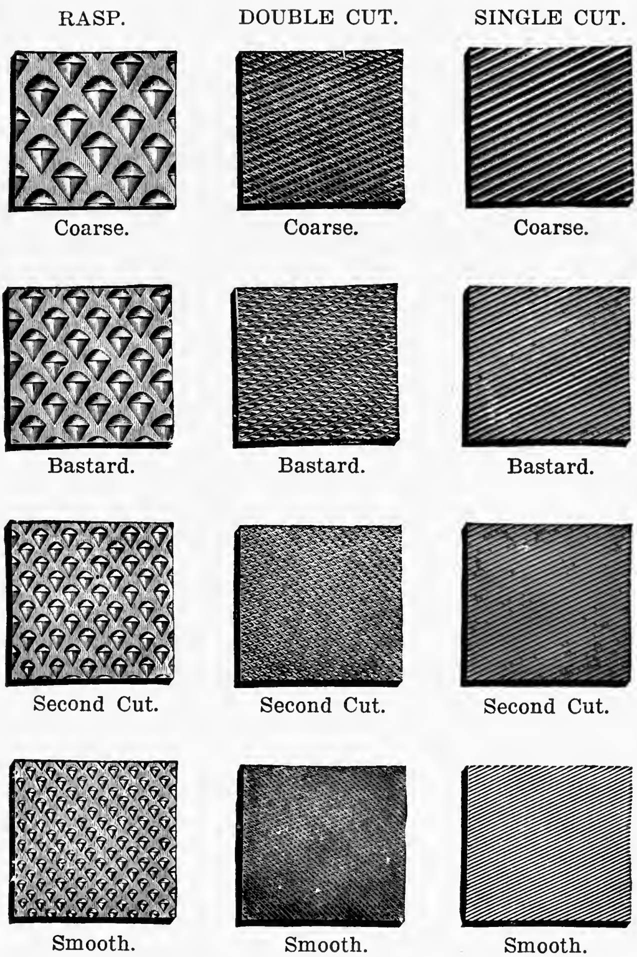


FIG. 207.—Styles of File Teeth.

including *half-round, crossing, tumbler, pit-saw, cabinet cross-cut* and *round;* and (c) triangular, including *three-square,* and *knife-edge.* Some rectangular files are smooth on one or both edges, and

mill or flat files may have slightly rounded edges. Fig. 208 shows the cross-section shape of files most used. These are:

(1) Flat.
(2) Mill.
(3) Pillar.
(4) Warding.
(5) Square.
(6) Round.
(7) Half-round.
(8) Three-square.
(9) Knife-edge.
(10) Cabinet.

In length (measured from the heel, or where the tang begins) files may be blunt or tapered, and the usual lengths of machine-shop files vary from 3 to 20 inches. Smaller sizes of files for special uses are known as *needle files.*

Another type of file has recently come to the notice of machinists. This is a single-cut file with the cuts arranged in arcs across the length of the file.

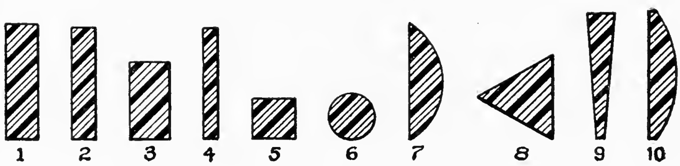


FIG. 208.—Cross Sections of Files.

358. Taps and Dies.—Thread cutting is more accurately and economically done by machine, but necessity frequently arises for cutting threads by hand. Taps and dies for hand work are made in many forms and sizes, of various standards of threads. They are usually made for cutting right-handed threads, as left-handed threads are used only for some particular requirement.

Fig. 209 shows a common type of machinists' hand taps for threading nuts. No. 1 is a *taper* tap, which may be used to ream out a hole and start the cutting of threads gradually, distributing the wear along the tap. No. 2 is a *plug* tap used for quicker cutting than No. 1. No. 3 is a *bottoming* tap used after No. 2 for cutting threads to the bottom of a hole.

A convenient form of die for bolt threading by hand is that shown in Fig. 210. This consists of a holder, made up of several parts, and four cutters. An extra set of cutters, or "chasers," is shown beside the die. These cutters may be adjusted to suit rods

FIG. 209.—Taps.

FIG. 210.—Threading Dies.

varying about 1/32-inch in diameter and may be readily removed for renewing. Fig. 211 shows a die-stock *A* used for holding and turning the die, and an adjustable tap wrench *B* for turning the taps of Figs. 209.

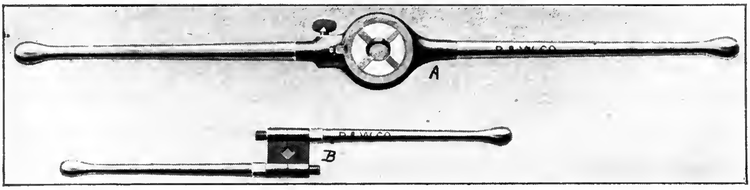


FIG. 211.—Die Stock and Tap Wrench.

All taps and dies are marked with the diameter of bolt and nut they will cut, the number of threads per inch, and the class or standard to which the thread belongs.

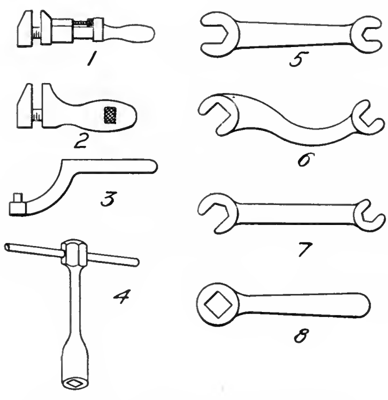


FIG. 212.—Forms of Wrenches.

359. Wrenches.—Hand wrenches for tightening or loosening nuts are of several forms, some of which are shown in Fig. 212. The wrenches shown are designated as follows:

(1) Monkey wrench (adjustable).
(2) Pocket wrench (adjustable).
(3) Spanner wrench.

(4) Socket wrench.
(5) Double-end, straight, open, hexagon wrench.
(6) Double-end, "S," open, square wrench.
(7) Double-end, angle, open, hexagon wrench.
(8) Single-end, closed wrench.

360. Scrapers.—To bring perfect contact between two metal surfaces, each is coated with a fine film of red lead and oil, and the surfaces are then rubbed together. Upon separating them, the high spots may be plainly seen, and are removed by hand scraping. The scrapers used are very hard pieces of steel, not unlike files without teeth, as shown in Fig. 213. The faces are ground true to form, either flat or curved, and the ends are ground blunt,

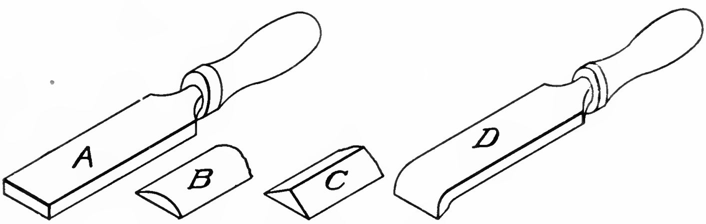


FIG. 213.—Scrapers.

except that the end of *D* is at more or less an acute angle to the surface. This grinding makes sharp edges at the end of the scraper and the scraping is done with these edges.

Bearings are scraped to fit journals by this method, and plane surfaces which move upon each other or must form a close joint for steam or other pressure connections, are brought to close contact by the same method. Scraping is always done for such fitting after the parts have been finished as accurately as can be done by machining, so that the amount of scraping needed will be reduced to a minimum.

Modern machines for grinding plane and curved surfaces are so perfected as to make hand-scraping unnecessary.

361. Surface Plates.—For testing the accuracy of a surface which must be exactly plane, one of the surface plates, shown in

Fig. 214, is used. These plates are sold in pairs so that one may be a test of accuracy of the other. When a plane surface is to be tested, one of the plates is smeared with a thin coat of oil colored slightly with red lead. This coating is spread evenly by rubbing both plates together and then the surface to be tried is rubbed over the oiled surface of one of the plates. High spots will be revealed by the oil coating, and these are scraped down.

The making of surface plates requires that each of three plates shall be scraped to fit the other two to insure plane surfaces.

362. Abrasive Materials.—These are used for polishing metal surfaces by grinding away the marks left by the file or by machine-cutting tools. They are frequently seen in the forms known as emery, carborundum, and crocus cloths. These are made up of a cloth of considerable strength, covered on one side with fine

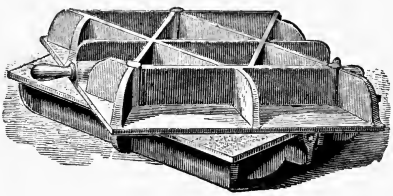


FIG. 214.—Surface Plates.

particles of the abrasive material, held by a coating of glue. These cloths are numbered according to the coarseness of the grains glued thereon. Crocus cloth is covered with red oxide of iron, and is used for fine polishing.

Powdered grinding materials are also frequently used mixed with oil for grinding between two metal surfaces in contact.

363. Portable Tools.—There is frequent necessity for drilling and other cutting on work which cannot be moved to a machine. There have been devised many types of small portable machines, usually designated as portable tools, which can be readily transported to large work for effective use in drilling, chipping, grinding away rough places, and cutting-off.

For machine-shop use the list of portable tools generally consists of the following viz.:

(1) Various types of portable drills driven by electric or pneumatic power or by hand. The ratchet drill for hand drilling is the simplest and lightest of these types.

(2) Portable boring bar, motor driven, for boring the stern bearings of ships before launching.

(3) Valve re-seating machine, hand or electrically driven, for truing up the seats of valves which have become leaky in use. This is done without removing the valve body from its pipe line.

(4) Pneumatic hammers for driving a cold chisel for many kinds of surface or edge chipping and for cutting a narrow path across a piece of metal in cutting it off.

(5) Pneumatic and electric grinders. These are essentially small grinding wheels mounted on a suitable shaft so supported that the machine can be held in the hands and the revolving wheel pressed against the spot to be ground.

(6) The oxy-acetylene blowpipe. This is used to direct its flame along a path on a metal plate, burning its way through the plate. It is used for many cutting operations in bridge, boiler, ship and other work, and is very useful as a portable cutting apparatus, though it of course leaves rough edges at the sides of the path burned through by the flame.

(7) Very useful also in various shops are lifting jacks and the differential pulley.

Jacks are made for lifting either by screw or hydraulic power. They exert great force and can be operated usually by one man. A hydraulic jack which will lift 50 tons a distance of 18 inches weighs about 325 pounds and can be carried by two men. Dilute alcohol is much used in the hydraulic jack because it does not freeze, but it lacks the desired quality as a lubricant.

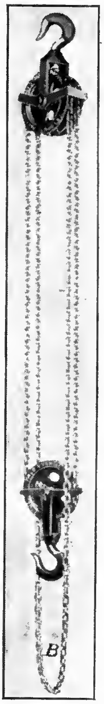


FIG. 215. Differential Pulley.

The differential pulley, shown in Fig. 215, may be operated by one man to lift weights ranging considerably beyond a ton, according to its capacity. It consists of a double-sheaved wheel, or block, at the top and a single-sheaved wheel below. An endless chain is rove over these sheaves. The distance between the two wheels is increased or decreased by pulling one side or the other of the loose part, or bight, B of the chain. The lifting power is due to the fact that the two sheaves of the upper wheel are of slightly different diameters.

364. Pipe Fitting.—This is the term used to designate the work of putting together various lengths of piping and their connecting parts. This work is associated with the machine shop, where the required lengths of piping are usually cut and threaded. The connecting parts are known as *fittings*. They are made in certain standard forms as a branch of re-manufacturing, and are kept in quantities among the supplies of the machine-shop store-room.

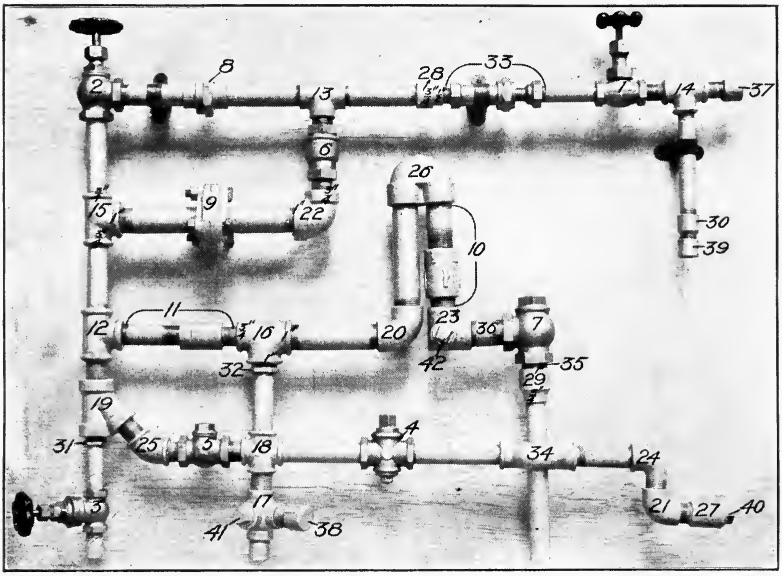


FIG. 216.—Example of Pipe Fitting.

The piping, used so extensively for conveying steam, water and gas, in many requirements other than those of engineering, is described in the chapter on the re-manufacture of metals. The standardization of the sizes and threads of fittings to agree with standard sizes and threads of piping makes it possible to use together the fittings and piping of all manufacturers. However, difficulty is occasionally found in pipe-fitting work due to the fact that the slightly tapered threads on both pipe and fittings are cut too deep or too shallow.

Reference No.	Fitting.	Size.	Style.
1	Globe valve	½″	
2	Angle valve	¾″	
3	Gate valve	½″	
4	Plug cock	¾″	
5	Horizontal check valve	¾″	
6	Vertical check valve	¾″	
7	Angle check valve	1″	
8	Screw union	¾″	
9	Flange union	1″	
10	Long screw	1″	
11	.....do	¾″	
12	Tee	¾″	Malleable, beaded.
13	.....do	¾″	Malleable, plain.
14	.....do	½″	Malleable, beaded.
15	Bull-head tee	¾″x1″	Do.
16	Reducing tee	¾″x1″x1″	Do.
17	Four-way tee	¾″	Malleable, plain.
18	Cross	¾″	Malleable, beaded.
19	Y-branch	¾″	Cast iron.
20	Elbow	1″	Malleable, plain.
21	.....do	¾″	Do.
22	Reducing elbow	¾″x1″	Cast iron.
23	Side-outlet elbow	1″	Malleable, plain.
24	Street elbow	¾″	Malleable, beaded.
25	45° elbow	¾″	Do.
26	Return bend	1″	Cast iron.
27	Sleeve coupling	¾″	
28	Reducing coupling	½″x¾″	Malleable, plain.
29	.....do	¾″x1″	Do.
30	Extension piece	½″	Do.
31	Bushing	½″x¾″	
32	.....do	¾″x1″	
33	Expansion joint	½″	
34	Cross-over	¾″	Malleable, beaded.
35	Shoulder nipple	1″	
36	Long nipple	1″	
37	Cap	½″	
38	.....do	¾″	
39	.....do	½″	
40	Plug	¾″	
41	.....do	¾″	
42	.....do	¾″	

Pipe threads are usually right handed, though left-hand threads are used for special purposes. The pipe ends are always threaded on the *outside* and most of the fittings are threaded to screw on the pipe end, although some fittings are made with outside threads to be screwed into other fittings. In connecting pipe and fittings, the threads are swabbed with a mixture of oil and graphite to make a tight joint which may be taken apart any time afterward.

365. Fittings.—Fig. 216 is a specimen of pipe-fitting work made up to show the use of various types of fittings. The kind, size, and style of each fitting is given in the preceding list.

Fittings are usually made of brass, cast iron, or malleableized cast iron. The malleableized cast-iron fittings are known as malleable fittings and are adapted to high pressures. They are made in two styles known as *beaded,* with a rolled rim at the opening of the fitting; and *plain,* without this rim.

Cast-iron fittings are much more bulky than the malleable fittings and are used for pressures not over about 150 pounds as they are not elastic, although they may not burst under many times that pressure. Brass fittings (known as composition fittings) are used for their ornamental appearance.

Iron fittings are either *black* or *galvanized.*

Pipe fittings of large size or for use under high pressures are made with flanged instead of screwed ends. Special fittings are made for hydraulic pipe connections.

366. Tools Used in Pipe Fitting.—The hand tools ordinarily used in pipe work are shown in Fig. 217. The pipe vise holds pipe for cutting, threading and fitting parts together. The tongs and wrenches grip the pipe for holding or turning. Dies, made with standard threads, are held in the die stock when in use. Each size of pipe die has a bushing which fits in the stock behind the die to steady the stock on the pipe end.

367. Bolts, Nuts and Machine Screws.—These articles are products of the re-manufacture of metals. Those for general use are made according to adopted standards of shape and size.

A machine screw is a small bolt with a slot in the head to be turned by a screw driver. Machine screws are made in diameters

designated by gage numbers, and varying over a range from about 1/16 to ½ inches in diameter. Machine screws with nuts are called stove bolts.

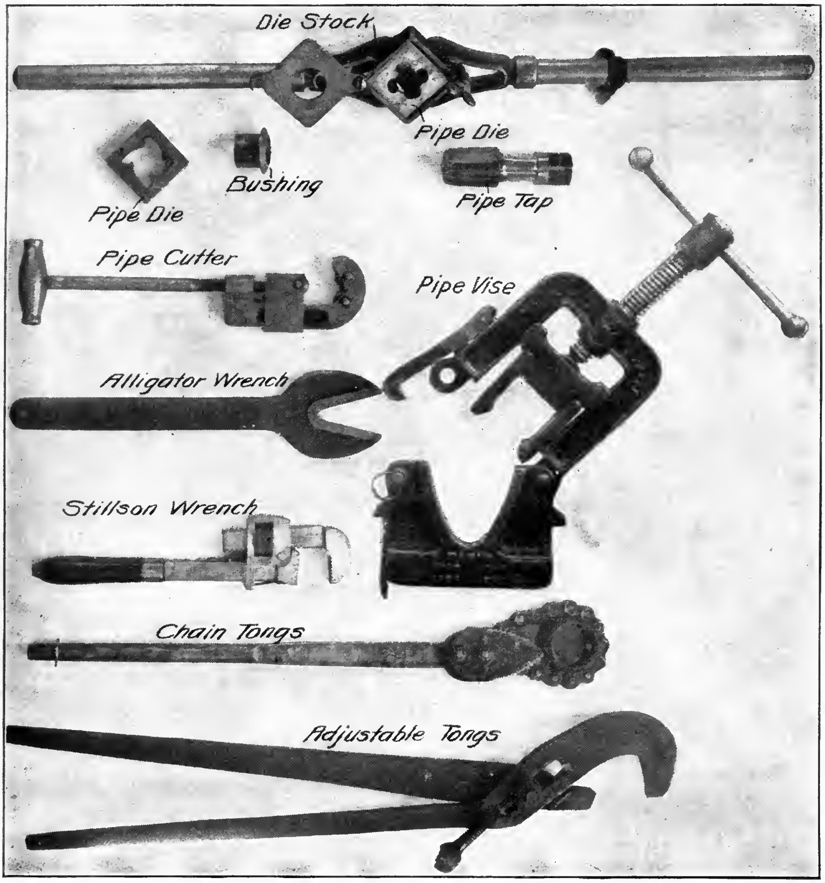


FIG. 217.—Pipe-Fitting Tools.

Bolts are standardized in the following items, viz.:

(1) Length.
(2) Diameter.
(3) Threads per inch for a given diameter.
(4) Shape and dimensions of head.

Nuts are standardized in shape and dimensions. A nut is usually larger than the head of its bolts as it is essential that the side of the nut through its smallest part should be large enough to give it the strength needed.

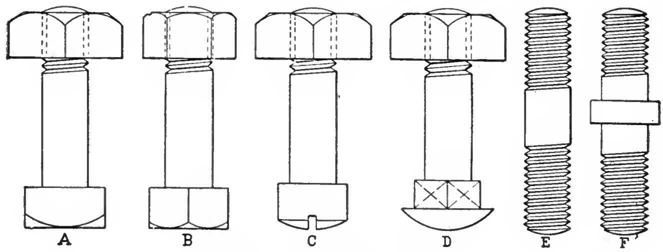


FIG. 218.—Standard Bolts.

Fig. 218 shows the usual types of standard machine bolts. These are designated as follows, viz.:

A. Machine bolt, square head and nut.
B. Machine bolt, hexagon head and nut.
C. Machine bolt, round or fillister head.
D. Carriage bolt.
E. Stud bolt.
F. Stud bolt with collar.
G. Tap bolt or cap screw (the same as *A*, *B*, or *C*), without nut and with longer thread.

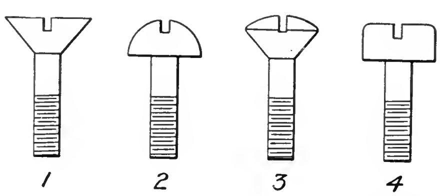


FIG. 219.—Forms of Machine-Screw Heads.

Fig. 219 shows the usual forms of machine-screw heads. They are designated as follows:

1. Flat or countersunk.
2. Round or button.
3. Oval countersunk.
4. Fillister.

Among the special forms of bolts may be mentioned the following, viz.:

(1) The *body-bound* bolt, also called the *tight-fitting* bolt, is one which is turned in a lathe to fit closely a bored hole. Bolts of this kind are much used in holding together parts of machinery to prevent the slightest change of position of one part on another.

(2) The *set screw* is used to screw through the hub of a wheel and press against the shaft to hold the wheel in place. It has many other similar uses. It resembles a tap bolt, and is either pointed or cupped at the end to take good hold against the shaft.

(3) The *expansion* bolt is used for bolting brackets and fixtures to a stone, brick or cement wall. The bolt has an expanding nut which is placed in a hole dug in the wall. When the bolt is screwed in tightly, it expands the nut and makes it press tightly in the hole.

The length of a bolt does not include the head, except in the case of bolts with countersunk heads. It is generally understood that bolts have standard right-hand threads, and if bolts with left-hand, double or other than standard threads are desired they must be specified.

To prevent nuts jarring loose and unscrewing, various nut locking devices are used.

CHAPTER XII.

THE BOILER SHOP.

368. Work of the Boiler Shop.—The work of building a boiler is partly that of shaping flat steel plates into cylindrical and flanged forms, and partly that of assembling with these forms certain products of other shops, as tubes, corrugated furnaces, stay bolts, etc. The whole assemblage composing the boiler proper is fastened together by rivets, screwed stays, and expanded tube ends; and when ready for use the boiler is supplied with such fixtures as the uptake and the smoke pipe, which are built in the boiler shop, and with such fittings as steam gage, stop valve, safety valve, etc., furnished by other shops.

369. Types of Boilers. Their Manufacture.—The many types of boilers may be classed under two general divisions, viz.:

(1) Shell or fire-tube boilers.

(2) Pipe or water-tube boilers.

The shell boiler is made in several forms, of which the locomotive and the cylindrical or Scotch marine types are familiar examples. In general design the shell boiler is in the form of a cylindrical shell which is a reservoir for the water and steam. Attached to the shell, and more or less surrounded by it are (1) a fire box, or one or more cylindrical steel furnaces and their combustion chambers, and (2) a nest of tubes opening from the fire box or combustion chambers into the smoke pipe.

The water-tube boiler consists of an assemblage of straight or bent tubes, the ends of which open into water and steam reservoirs usually designated respectively as headers and drums. The water and steam are contained in these tubes, headers and drums, and the boiler is surrounded by a sheet-steel casing which confines the fire and smoke within its limits. A space for the furnace is provided under the tubes and the flame and hot gases pass among the tubes to reach the smoke pipe.

The shell boiler held supremacy for many decades as a steam generator after the steam engine came into use, but demand for

the economy of higher steam pressures has gradually brought into use many types of the water-tube boiler, which is particularly adapted to standing high pressures. This change has taken away much work from the shop for building shell boilers. The building of water-tube boilers consists in a great measure of the assembling of the products of other shops and plants, and of the making of certain parts by the cold or hot pressing of mild steel plates to special forms, leaving very little work to be done, for this type of boiler, by the methods and machines used in the building of shell boilers.

The many patented types of water-tube boilers have brought about the building of these boilers as special work, and many of the processes of forming the headers and other parts of a particular type of boiler are unique and ingenious methods of hot and cold pressing and of welding by aid of electric, furnace, and gas blow-pipe heat.

In some patented boilers the parts are made up more or less of cast steel, or even of cast iron for pressures not over about 100 pounds.

Many shell boilers for high and low pressures are still built for marine, locomotive, and stationary uses, also the larger drums and some other parts of water-tube boilers are built in the shop equipped for shell-boiler work, hence the boiler shop and its equipment continue to be an essential part of a general manufacturing plant.

The improvement in recent years of boiler steel enables shell boilers to be built for higher pressures than formerly.

370. Boiler Material.—The material used for plates, rivets, braces, and all other parts on which the structural strength of a high-grade boiler depends are made of a low-carbon open-hearth steel in which is allowable only very small quantities of phosphorus and sulphur. Nickel is often alloyed with this steel to improve its tensile and elastic strength.

The elastic strength, rather than the tensile strength of the material, is of first importance, as the permanent safety of the boiler depends upon all stresses remaining within the elastic limit. A good margin between the elastic and the final strength of the material provides a ductility or elongation which will many times save actual and disastrous disruption under pressure by allowing

the material to bulge out or otherwise stretch greatly before it breaks.

Specifications for high-grade boiler plate require an elastic strength of about ½ the tensile strength, a tensile strength of about 70,000 pounds, and an elongation, when pulled apart, of about 25% in a test bar 8 inches long. Rivets, bolts, and material for boiler braces are required to exceed slightly the requirements specified for plates. Plates which are to be flanged for parts of the boiler structure must be ductile to a high degree, and specifications usually require the test piece to show a slightly greater per cent of elongation and allow slightly less tensile and elastic strength than for other plates.

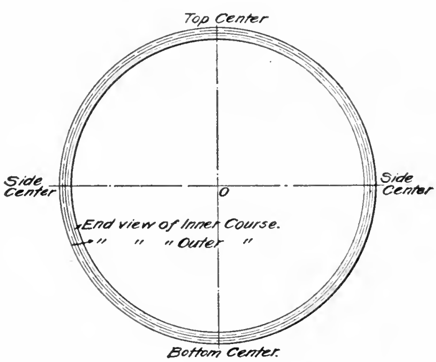


FIG. 220.

371. Preliminary Diagram for Laying Out Work.—The dimensions and all details of a boiler to be built must be shown on suitable drawings for the guidance of the master boilermaker in laying out and directing the work of building the boiler. Supposing a cylindrical shell boiler is to be built, the drawings supplied must give at least a longitudinal and a transverse cross section of the boiler, besides views of the side and one or both end elevations, and sufficient enlarged views of single or combined parts to show the details of their construction.

From the drawings he proceeds to mark out to full or half size on a smooth laying-out board provided for the purpose, the front end of the boiler. The beginning of this work is shown in Fig.

220. Through the center, O, of the boiler, draw the horizontal and vertical lines as guides for laying down all parts of the boiler head and the openings therein. This board serves also to show on a large scale the relative positions of interior parts of the boiler, particularly the positions of the plates composing the combustion chambers.

The shell of the boiler is composed of two or more rings or courses of plates, each course consisting of one or more plates, as

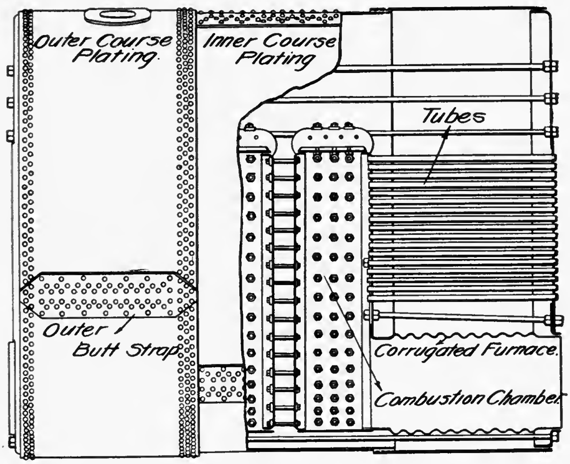


FIG. 221.—Double-End Cylindrical Boiler.

shown in Fig. 221. The plates in each course are butted end to end, and are fastened together by butt straps on both sides of the plates. An outer butt strap is marked in the figure. Two adjacent courses are joined together by overlapping the ends as shown, and the ends of the shell overlap the heads.

Referring to Fig. 220, the full-line circles represent the ends of the inner and outer course plates, and the dotted lines represent the neutral circles of these plates by which their curvatures are figured from the flat plates from which they are made. The lines through the center O divide the diagram into quadrants, determining four points of reference for laying out the shell.

372. Diagram for Laying out Shell Plates.—The shell is developed on a flat surface, the position of each plate joint is marked with reference to the top, bottom, and side center lines, which are the first lines placed on this diagram, and the amount of lap for the plates of each adjacent course is marked. All details of rivet and other holes are transferred to this diagram, which is used for marking each shell plate and their butt straps. Each end of each plate is numbered when it is measured up, to insure placing it in its proper location.

The developing of the shell is virtually cutting it along one of its cylindrical elements and unrolling it until it lies flat. This development is made as if the outer courses unrolled without stretching the circumference of their neutral circle, but the inner course neutral circle is supposed to be stretched until it equals the length of the outer course circle in the flat diagram.

In marking off rivet holes around the girth of the shell, care must be taken to space them so that they will be at equal distances apart around the circle.

The distance between centers of adjacent rivet holes is called the *pitch* of the rivets.

373. Preparation of Plates for Laying Out.—Boiler plates are ordered from the rolling mill as flat plates. Their dimensions are determined from the drawing of the boiler, and the plates ordered should be near their finished dimensions, leaving a margin of about once the thickness of the plate to be trimmed off around the edges. The trimming of this margin by chipping or planing removes the strained metal along the edges caused by shearing the plate at the mill.

A few days before a plate is needed for laying out, it is selected from stock and pickled to loosen scale and to expose the clean surface of the steel. Pickling is done by immersing the plate on edge for about 24 hours in a wooden vat containing about 5% of hydrochloric acid in fresh water. When lifted out the plate is scrubbed and rinsed with clean water made slightly alkaline with lime to remove all acid.

A careful record of each plate, giving dimensions, weight, and data of its manufacture and tests, is furnished the master boiler-

maker. This record enables the selection of the particular plate intended for a certain place in the boiler.

Laying out consists of transferring to the clean surface of a plate the dimensions and lines shown by the laying-out diagrams and the original drawings. The location of lines and boundaries is marked on a plate by scribed lines and by center-punch marks.

374. Operations for Shaping Plates.—The operations for shaping boiler plates are as follows:

(1) Planing plate edges.
(2) Rolling plates to cylindrical form.
(3) Flanging.
(4) Drilling holes for rivets, stay bolts, tubes, etc.

These operations prepare the plates for assembling, although a few rivet holes are drilled immediately after the plates are marked,

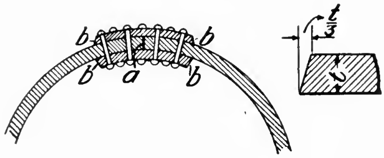


FIG. 222.

for the purpose of handling them. These holes are drilled slightly smaller than the finished size and their worn edges are reamed out when ready for riveting.

375. Planing Plate Edges.—Edges of shell plates are planed to the finished dimensions before the plates are rolled. When the boiler head is made up of more than one plate, the straight edges of these plates are planed, but the edges to be flanged are not planed. Flanged edges are chipped smooth by pneumatic chippers, or a circular-flanged plate forming a boiler or steam-drum head may have its flanged edge turned smooth in a large lathe.

Shell-plate ends which butt together must be planed at the correct angle to fit at both outer and inner edges when rolled to shape, as shown at *a*, Fig. 222. All free edges, as those marked *b* on the butt straps, are planed or chipped to a bevel for caulking, the usual angle of which is shown in the section of a plate edge of thickness *t*.

Fig. 223 shows a plate-edge planer. The plate rests flat, and the edge to be planed is clamped by the screw jacks J against the bedplate B of the machine. The clamping beam C is held rigidly by the housings H. Two saddles, S and T, which travel along the

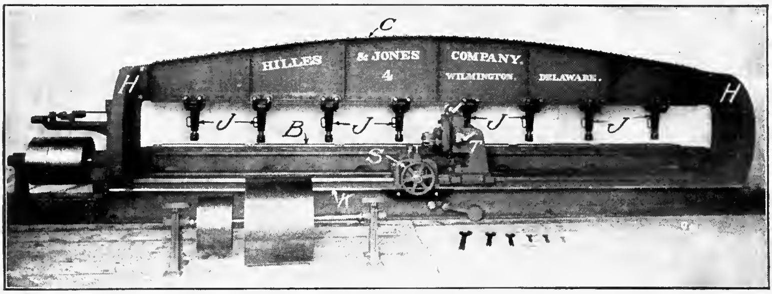


FIG. 223.—Plate-Edge Planer.

bedplate, carry the cutting tools. The saddle S carries two tools and cuts in both directions of its travel. The saddle T carries but one tool which may be fed vertically during its horizontal motion. The saddles are used separately. The bar K is an automatic reversing bar for reversing the motion of the two-way cutting saddle.

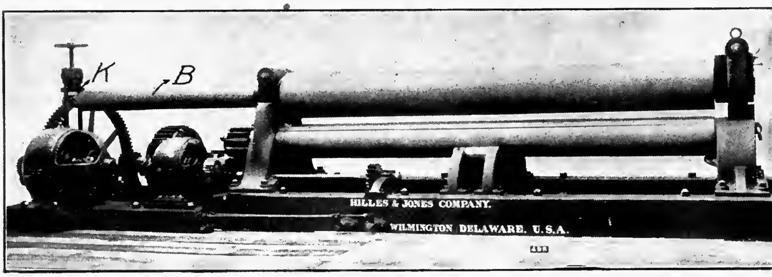


FIG. 224.—Plate-Bending Rolls.

376. Plate-Bending Rolls.—This name is given to the machine shown in Fig. 224 to distinguish it from the plate straightening rolls. The machine consists of three solid-forged rolls supported parallel in heavy bearings. The lower rolls are driven by gearing

and the upper roll revolves from contact with the plate rolled. The upper roll may be raised or lowered to suit the thickness of the plate and the curvature to which it is rolled. In case a sheet is rolled into a complete cylinder, it is removed by lifting one end of the upper roll and sliding the cylinder out. To do this, the yoke K is screwed down against the extension bar B until the other end of the roll and its bearing are lifted out of the way.

Plates are rolled cold, and are run back and forth until the curvature gradually increases to that of a template made as a guide.

The rolls cannot bend a plate for a short distance from each end, as shown by the diagram in Fig. 225. Suppose the plate to be

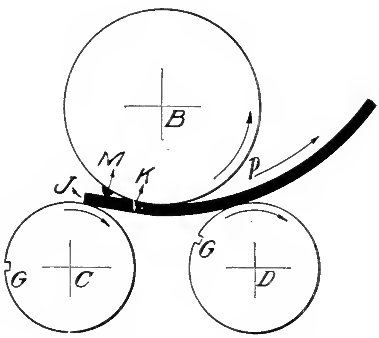


FIG. 225.

moving in the direction of the arrow p. That part of the plate between its contact points with the rolls B and C is not bent, as bending takes place only after the plate passes the first contact point K with the roll B. When the plate reaches such a position that the end J has passed over the crest of the roll C and begins to drop, practically no further bending will take place between the end and the point K. In shop practice, this difficulty is obviated by placing a bar of half-round iron at M and rolling it against the plate.

The lower rolls have one or more longitudinal notches, as at GG, to grip the edge of the plate when started in the rolls, or to flange the ends of narrow strips of plating when needed.

Plate-bending rolls are also made to operate in a vertical position, and are known as vertical-bending rolls.

377. Marking a Flange.—In boiler making and in sheet-metal work generally, a flange is a margin of metal along the edge of a plate turned at a greater or less angle out of the plane of the plate.

Fig. 226 shows a cross section of a flanged circular plate with the dimensions which would be given by a drawing. The lettering has been added for purposes of explanation. AB is the center line of the drawing, M is a point at the end of the curve of the flange, t is the thickness of the plate, and r is the radius of the inner

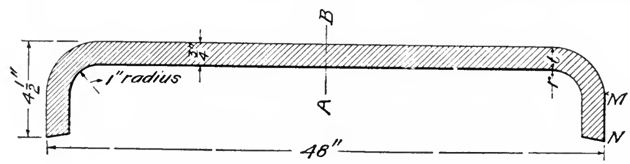


FIG. 226.

curvature of the flange. The distance $r+t$ is called the "draw" of the flange.

The marking of the flat plate, shown in Fig. 227, consists of locating the point M so that it will be 24 inches from the center line AB when the flange is turned. From C as a center describe on the plate a circle with a radius of $24+\frac{r+t}{4}$ inches. This circle is marked with a series of center-punch marks, as at M', as a guide to the workman in turning the flange, and these punch marks must be turned into the position occupied by M in the upper figure. The

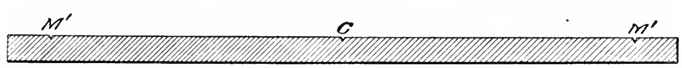


FIG. 227.—Marking a Plate for Flanging.

plate must have sufficient diameter to allow for the flange width MN of 3½ inches, plus a small amount for chipping to a smooth-beveled caulking-edge. The distance $\frac{r+t}{4}$ is arbitrarily added in shop practice to the radius prescribed by the drawing as an allowance for the change of position of the punch marks when the flange is turned.

378. Methods of Flanging.—Flanges may be turned (1) by beating down the plate edge with hand mauls, while the plate is

suitably held on a former or between two heavy bars, or (2) by the hydraulic flanging machine. Plates are usually heated to a bright red along the edge to be flanged. Several heats may be necessary to flange the edge of a large plate, as only 3 or 4 feet can be heated along the edge at one time and flanged before undue cooling.

Flanged plates must always be annealed after flanging is completed as the flanging heats are local and they set up internal

FIG. 228.—Flanging Clamp.

stresses in the metal. Large plates partly or wholly flanged may crack if left to cool over night unannealed, hence it is well to keep plates hot, or at least warm, until final annealing can be done.

379. Equipment for Flanging by Hand.—Fig. 228 shows a flanging clamp for holding plates for straight flanging. Angle bars of various curvatures over their angles are furnished for placing over the lower clamp to give the desired curvature to the

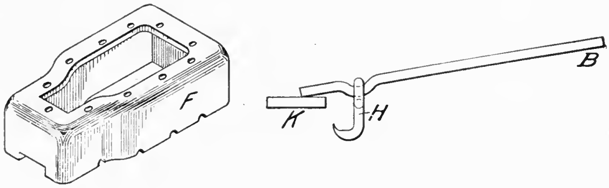


FIG. 229.—Flanging Former.

flange. When the plate is clamped, the flange is beaten down and finished to shape by hard-wood mauls and other hand tools.

Fig. 229 shows a cast-iron former F made for flanging special shapes. The sheet to be flanged must be held down either by bolts which can be quickly adjusted or by some other means such as the bar B, hook H and iron block K. The hook can be quickly hooked

under the edge of the former, and the block is pressed securely on the plate.

Heavy hickory mauls are used to beat the flange down, and long-handled flatters and fullers are used to shape the flange exactly after it is turned by the mauls. Sledges must be used with caution if at all, as they scar the flange and may endanger its strength or at least may cause a bad joint between the scar and the plate on which it laps.

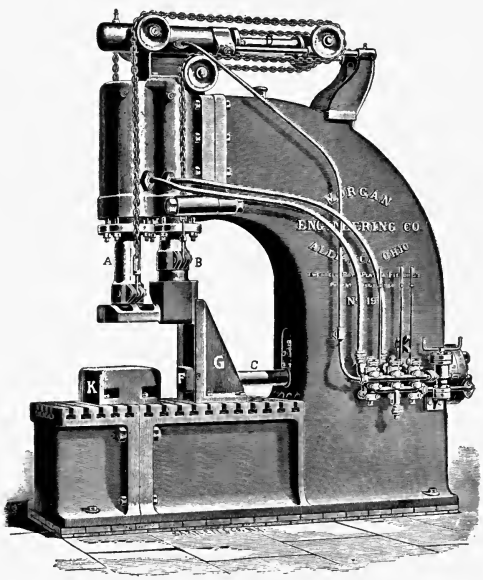


FIG. 230.—Hydraulic Flanging Press.

380. The Hydraulic Flanging Press.—This machine is shown in Fig. 230. It consists of a heavy cast-iron body carrying four hydraulic cylinders, and a suitable table on which work is held steady while being flanged.

The plunger head on the rod *A* of the outer vertical cylinder clamps the sheet to be flanged by pressing it against the former-block *K*. The head on the rod B is then forced down against the edge of the plate, turning it down against the right-hand edge of the former-block. The flat end *F* on the rod *C*, which is controlled

by the horizontal cylinder partly in view, is then forced against the flange to smooth it. The triangular block *G* serves as a guide to keep *B* in place as it descends.

The horizontal cylinder on top of the press is rigged merely to lift the heads carried by the vertical cylinders. The pressure in the cylinders *A*, *B* and *C* is admitted from the hydraulic accumulator and released by means of the hand levers on the side of the press. The upper cylinder is under constant pressure and acts similar to a spring.

When the edge of a circular plate is to be flanged, a heavy cast-iron pivot is bolted to the center of the plate and is dropped into a

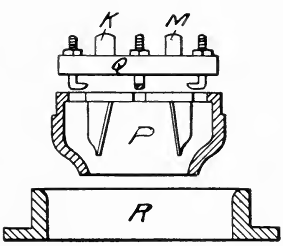


FIG. 231.—Former for Hydraulic Flanging.

socket on an extension piece bolted to the table of the press. In this way the turning of a flange truly circular is assured.

When necessary to flange the edges of a circular or an elliptical hole in a plate, the hollow former-block *R* of Fig. 231 is bolted to the table and the cross head *Q* is attached to both vertical cylinder rods by the projections *K* and *M*. This cross head carries the hollow flanging block *P*. By means of these fittings the flange entirely around the hole is pressed at one motion.

The degree of heating a plate edge must be carefully judged so that the metal will be pliable, yet not soft enough to be torn away by the downward pull of the flanging head.

381. The Hydraulic Accumulator.—The great pressures used in hydraulic machines are supplied from intensifiers on the principle of that shown with the forging press in a previous chapter, or from accumulators. Water in an accumulator cylinder is subjected

to a pressure of at least several hundred pounds per square inch by means of weights loaded upon the cylinder as shown in Fig. 232.

The description and operation of the accumulator here shown are given as follows, viz.: A heavy base B rests on a concrete foundation and supports the accumulator. This base carries a vertical steel rod R, called the ram, and short vertical supports S

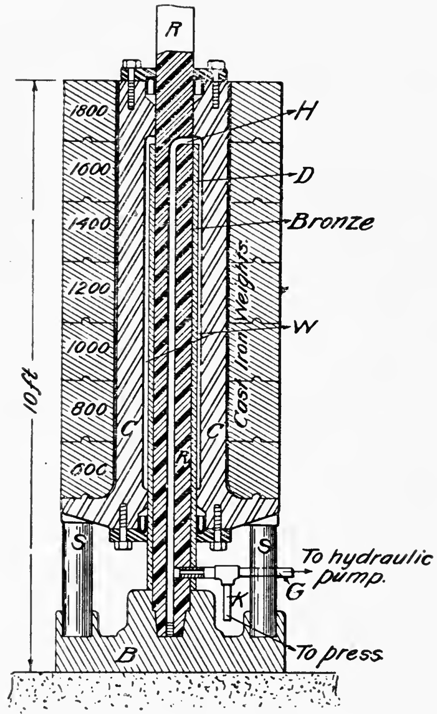


FIG. 232.—Hydraulic Accumulator.

on which the cylinder rests when not in operation. A bronze sleeve D, about $\frac{1}{2}$ or $\frac{3}{4}$ of an inch thick, is shrunk over the lower end of the ram. The ram has a hole along its axis as shown, communicating at H with the inside of the heavy cast-steel cylinder C. The upper end of the ram, which acts as a guide for the cylinder in its variable up and down travel, is steadied by the roof trusses of the building in which the equipment is installed.

Water is forced by hydraulic pumps (steam-driven pumps with very small water plungers) through the pipe *G* and the opening *H* into the space *W* between the rod and the cylinder. The unbalanced pressure on the end of the bronze sleeve *D* is increased by the pumps until it is sufficient to raise the cylinder and the weights which it carries. These annular cast-iron weights determine the degree of pressure in the cylinder. If less pressure is desired, one or more of the weights is lifted and suspended above the accumulator.

This pressure is used by transmitting it to the controlling valves of a hydraulic press through a pipe connected at *K*.

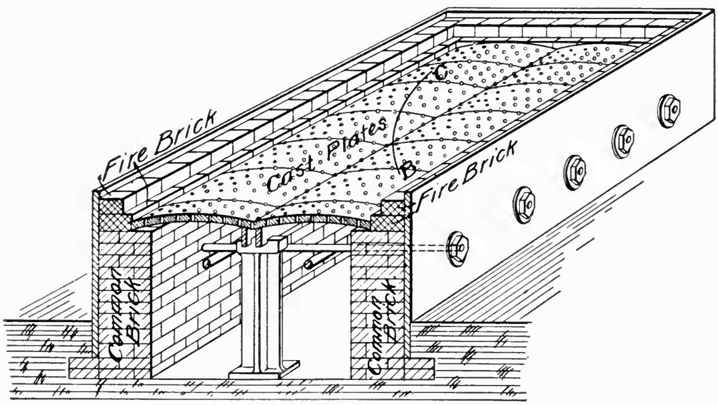


FIG. 233.—Flange-Heating Furnace.

Suitable automatic controls are rigged on the accumulator to stop the pumps when the cylinder has raised its full height, and to prevent a sudden drop of the cylinder in case a pipe should suddenly break.

382. Flange-Heating Furnace.—Fig. 233 shows a hearth or furnace, partly in cross section, for heating the edge of a plate for flanging. It is a brick-walled basin re-inforced around the sides with iron plates and covered with perforated plate sections as shown.

The furnace is operated as follows: Supposing a curved edge of a large plate is to be flanged, draw a chalk line *BC* about 5 feet long, representing the curve of the flange. The perforations along

this line and those within 3 inches on each side of it are left open as shown, but the remainder, over the entire surface of the plates, are stopped by dropping boiler rivets into them. Finely broken soft coal free from sulphur and clinker is dampened and packed in a layer about 8 or 10 inches deep over the rivet-covered perforations, leaving the open perforations about *BC* uncovered. A fire of high-grade soft coal or preferably coke, is built along *BC* over the open perforations, and the air blast is turned into the hollow space beneath the plates. The air is free to escape only through the fire along *BC,* hence the fire is easily confined to this space. When a plate edge is placed over this strip of fire, it is covered by several blocks of wood and old pieces of sheet iron which confine the heat and facilitate heating the plate.

When a plate is flanged along two edges meeting at a corner, the corner flanging must be done at nearly a welding heat. The corner is rounded off before flanging to remove the excess of metal.

383. Straightening and Annealing of Flanged Plates.—The work of flanging usually warps a plate more or less, though the work of straightening can frequently be done before it goes to the annealing furnace. Flanged plates are placed in a large coal or oil-burning furnace, heated red, and drawn out on a level floor of cast-iron slabs to be straightened by mauls and flatters.

Annealing also takes place in a large furnace. The annealing heat is best gaged by a pyrometer, and it is the best practice to allow plates to cool gradually in the furnace by shutting off the fuel supply.

After annealing, flanged plates are then ready for marking with the location of rivet, tube and stay-bolt holes, which could not be marked before flanging, as a slight distortion of the plate would warp these marks out of position.

384. Drilling Holes in Boiler Plates.—Rivet and other holes in boiler plates must be drilled and not punched. Holes must be carefully located on the plates from the layout diagrams. Plates which are not to be heated for flanging or other purpose, as in the case of shell plates, may have the holes drilled as soon as they are laid out. It is well to bear in mind that, in plate edges which lap, rivet holes are drilled in one plate according to the lay-out

diagram, and these holes serve as guides for drilling the lapping edge of the other plate. When two plates are thus drilled in contact, they must always be taken apart afterward and the metal chips and burr (rough edge of the hole) removed, otherwise the joint would not be tight after riveting together.

The principal drilling machines of the boiler shop are multiple and portable drills. The multiple drill (also called the gang drill) is a vertical-drilling machine with several drill spindles mounted at adjustable intervals along a straight carrying bar. Portable drills are either pneumatic or electric driven, and are much used for drilling holes in plates after the parts of the boiler are assembled and temporarily held together by a few bolts. Portable drills save shifting the position of heavy boiler parts for drilling. The ratchet drill, for drilling by hand, is useful in confined spaces, but its work is slow.

Holes for boiler tubes, usually about 3 inches in diameter, are drilled in the tube sheets by a tube-hole cutter, which cuts a disc of metal from the hole instead of cutting this metal out in fine chips.

385. Assembling the Parts of a Boiler.—After the plates composing a boiler have been trimmed to finished dimensions, rolled to the required curvatures, flanged, and have had enough rivet and other holes drilled for bolting them together temporarily, the next step is to assemble them into correct relative position. The plates of the shell are first assembled in rings or courses, and the several courses are then assembled end to end; the combustion chambers and corrugated furnaces, which are placed inside a cylindrical boiler, are assembled complete in themselves, and when they are placed inside the shell, the boiler heads are placed in the ends of the shell.

As each group of plates is assembled, rivet holes are drilled in the lapped edges at the seams, the plates are taken apart, cleaned, re-assembled and finally riveted permanently together.

The combustion chambers are held rigidly in place in the boiler by suitable stay bolts which fasten them to the shell, or fasten adjacent chambers to each other. (See Fig. 221.) The tubes join the combustion chamber to the boiler head and serve to increase the

rigidity of the combustion chamber while fulfilling their purpose of conducting gases of combustion from the furnace to the smoke pipe. Tubes are placed after all other parts are assembled and riveted, and after the screw stays are placed.

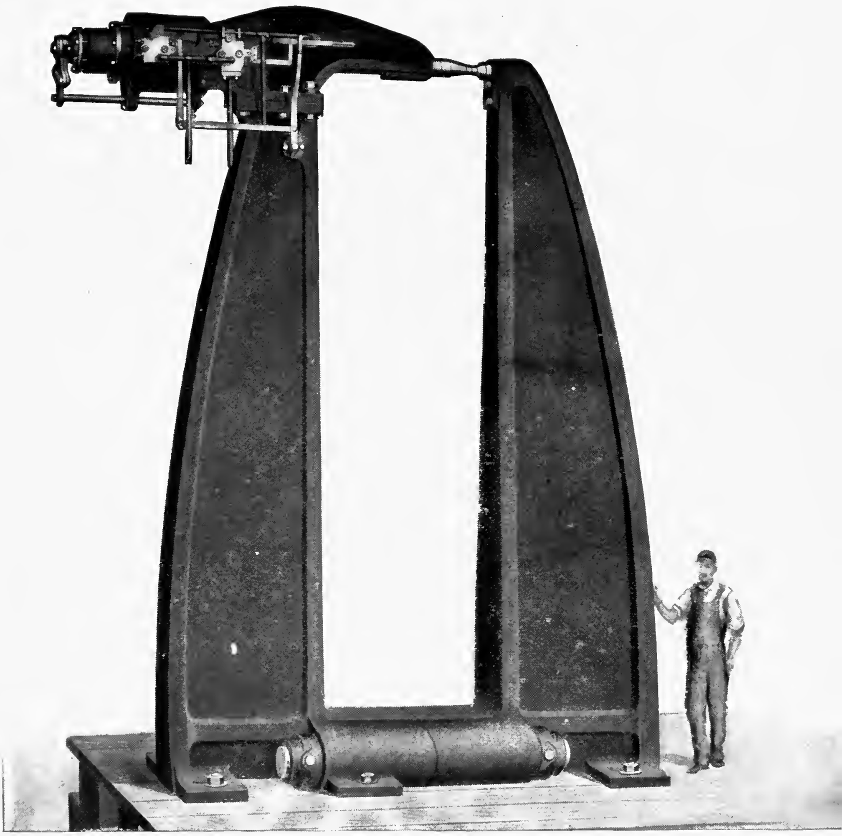


FIG. 234.—Hydraulic Riveting Machine.

386. Riveting.—Riveting is done by (1) hydraulic riveting machines, both stationary and portable; by (2) portable pneumatic riveters, and by (3) hand hammers. Portable hydraulic riveters are massive and must be carried and held in place for their work by a crane.

Fig. 234 shows a type of powerful stationary hydraulic riveter. This is used to rivet the shell plates together and to rivet one head in the shell. The shell is suspended, with its axis vertical, by chains attached to a crane which is a part of the equipment of this machine. The riveting dies, closed together in the view, are opened to allow work to be suspended in the gap between the two arms of the machine, the arm on the right projecting up inside the shell. The die is placed as high on the right arm as possible to allow it to be used in riveting boiler heads and other flanged work. The hydraulic cylinder is so arranged that three different pressures, 50, 100 and 150 tons, may be exerted on rivets of various sizes. The men who operate the machine stand on a platform, not shown, built near the top of the arms. Heated rivets are passed up from a small furnace at the base of the machine.

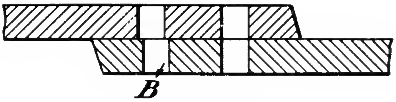


FIG. 235.

Portable pneumatic riveters are much used for bridge, ship and boiler work. They are held in the hands of the workman and may be operated in confined spaces too small even for driving rivets with hammers. These machines are supplied by air at a pressure of about 60 pounds per square inch, led through a hose from an air compressor. Rivets are held in place while driving by a man or boy who presses a sledge hammer or other mass of iron, suitably supported, against the rivet head. Pneumatic *holders-on* are also used for this purpose.

Careless or fraudulent work in laying off and drilling rivet holes will bring about a lack of coincidence of two holes as shown at *B* in Fig. 235. If the relative displacement is slight, it may be remedied by careful re-drilling or by reaming. A bad practice is to drive a tapered steel pin into the hole to enlarge it (called "drifting"), and then to put in a small-bodied rivet to cover up the defect.

387. Rivet-Heating Furnace.—Rivets are heated preparatory for driving in a forge, or more efficiently in a small oil-burning furnace, a type of which is shown in Fig. 236. This consists of a small sheet-steel box, lined with fire brick, mounted on its fuel tank. Through the small hole in the end of the furnace an atomizer sprays oil into the flame which is maintained by the burning of this spray. The atomizer, or burner, is connected to its fuel tank and to a com-

FIG. 236.—Rivet Heater.

pressed air tank which supplies furnaces with air at a moderate pressure.

388. Methods of Holding Boiler Tubes in Place.—Fig. 237 shows the method of holding tubes in a shell boiler. The ends of an ordinary tube are expanded to fit tightly against the sides of the holes in the tube sheets. The stay tubes, heavier than ordinary tubes, are screwed into the tube sheets. Stay tubes are spaced at intervals among the ordinary tubes to brace the tube sheets rigidly.

It is frequently the practice to flare or bead over the tube ends to insure tight joints.

Tubes of water-tube boilers are usually expanded into their headers. Very few water-tube boilers have screw tubes.

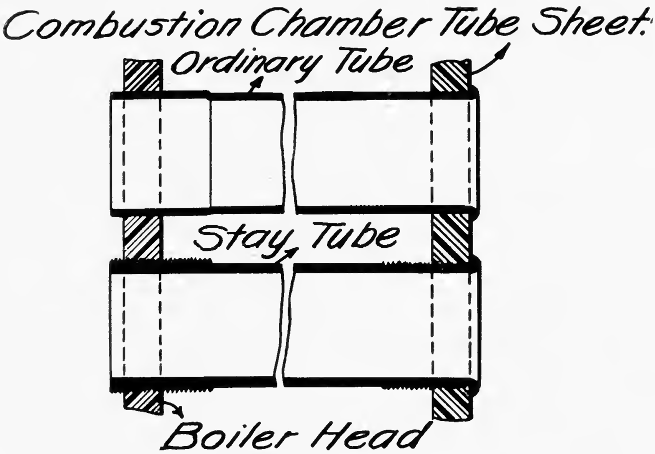


FIG. 237.—Method of Fastening Boiler Tubes.

Fig. 238 shows a tube expander for expanding tube ends. This consists of a sleeve *S* carrying three hard-steel rollers *R* in loose bearings, a cap *C*, and a tapered-steel pin *P*. The sleeve is placed in the end of the tube far enough to bring the edge of the cap

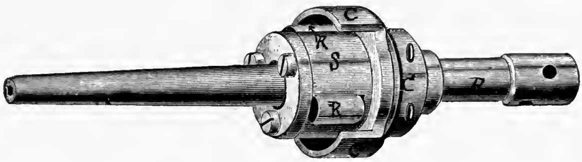


FIG. 238.—Tube Expander.

against the tube sheet. The steel pin is driven in fairly tight, and is revolved by a small steel rod placed through one of the holes at the end. The pin presses against the inner edges of the rollers *R*, and as the pin revolves it turns the rollers around against the

inside of the tube, expanding the end tightly against the hole in the sheet.

Beading is done by a beading tool, shown in Fig. 239. This tool may be struck by a hammer or operated by a pneumatic holder such as is used in chipping or riveting.

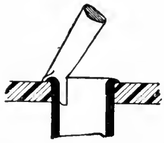


FIG. 239.—Beading Tool.

389. Chipping and Caulking.—After the riveting of a boiler is completed, the various lapped seams are made tight by caulking the beveled edges of the sheets. A flanged joint is usually made, as shown in Fig. 240, with the lap of the end D on the *outer* face of the flange and not on the inner face B except for a particular reason.

This arrangement enables the beveled edge of each sheet to be set down against the adjacent surface tightly, as shown at KK.

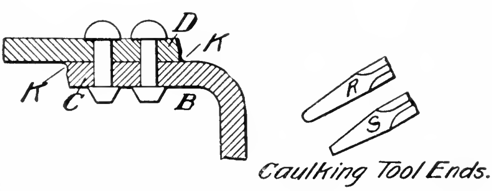


FIG. 240.—Example of Caulking.

This operation of caulking is preceded by cutting the edge of the plate to a uniform bevel. Flat-plate edges may be beveled by planing, though edges of curved flange plates are beveled by chipping with the cold chisel driven by the hammer or better by the pneumatic holder. Chipping may be done before or after the joint is riveted, and, if done after riveting, great care must be taken to avoid gashing the surface of the adjacent plate.

A caulking tool is virtually a cold chisel with a blunt end. Two styles of caulking-tool ends are shown at R and S in Fig. 240.

390. Corrugated Furnaces.—The locomotive type of boiler has a square fire box at one end, but the cylindrical type of marine-shell boiler is fitted with one or more corrugated furnaces such as is shown in Fig. 221. These furnaces are divided along the center by the grate bars, and they are corrugated to enable them to resist the collapsing pressure of the water which surrounds them in the boiler. Each furnace is usually about 40 inches in diameter and 7 feet long.

These furnaces are made in the United States only by The Continental Iron Works of Brooklyn, New York. Briefly, the process of making a furnace is as follows: A mild steel plate from the rolling mill is bent into a cylinder in the bending rolls. The two edges are lap-welded by passing the lap, at a welding heat, between two disc rollers pressed against the seam by hydraulic pressure. After welding, the cylinder is heated to a bright red heat in a furnace. It is then lifted by the crane and carried to the corrugating machine, the vertical rolls of which are suitably shaped to press the corrugations gradually on the cylinder as it revolves repeatedly between the rolls. After the corrugations are pressed, the end is heated and flanged to the shape required, and the whole furnace is then annealed.

These furnaces are always made to order.

391. Other Equipment for the Boiler Shop.—Besides the equipment so far named for this shop, the shop should have

(1) Power shears for shearing heavy steel plates up to about $1\frac{1}{2}$ inches thick.

(2) Power punch for punching holes in plates up to about $1\frac{1}{2}$ inches thick. This punch is not used for punching rivet holes unless they are afterward enlarged by drilling.

(3) Hand shears and punch, either in two machines or combined in one machine, for shearing and punching holes in plates of $\frac{3}{8}$-inch thickness or less.

(4) Hand pump of simple design for testing new boilers under hydrostatic pressure.

(5) Cranes and other lifting appliances such as are installed in the machine shop.

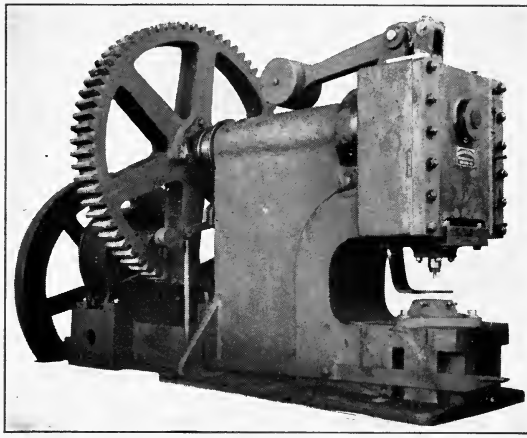


FIG. 241.—Vertical Power Punch.

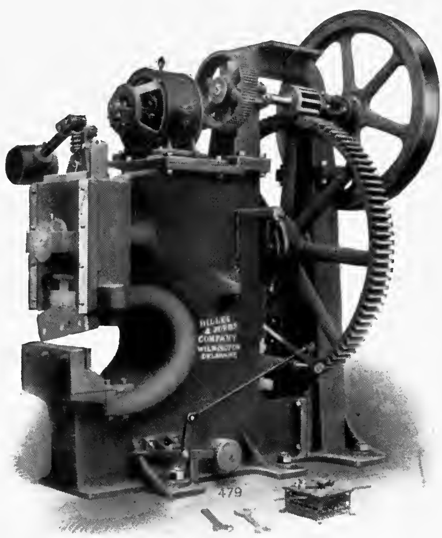


FIG. 242.—Vertical Power Shears.

392. Power Shears and Punch.—One type of these machines is shown in Figs. 241 and 242. Plates are held flat for shearing or punching in chain slings carried on the hook of the crane. Two men usually hold the plate to guide it under the machine at the direction of a third man who sets the machine in motion by means of a conveniently placed foot or hand-lever.

Punch and shears are often in one double machine, or, by a change of equipment, a punch may be changed for shearing, or vice versa.

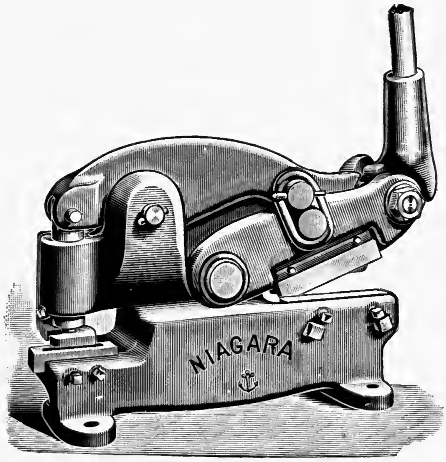


FIG. 243.—Hand Shears and Punch.

That part of a plate operated on by punch or shears is necessarily strained to a point of disruption. Metal on each side of a shearing line or around a punched hole is strained more or less according to its proximity to the line of disruption, and some of this metal is strained beyond its elastic limit, and hence is less strong than it was before. For this reason, when boiler plates are punched or sheared, a punched hole must be drilled larger, and the sheared edge must be planed or chipped away sufficient to remove the metal strained beyond the elastic limit.

393. Hand Shears and Punch.—Fig. 243 shows a convenient form of this machine. It may be bolted to a heavy bench or set on

a portable stand. Small punches are frequently fitted to be operated by hydraulic pressure.

394. Shapes of Rivets.—Fig. 244 shows the usual shapes of

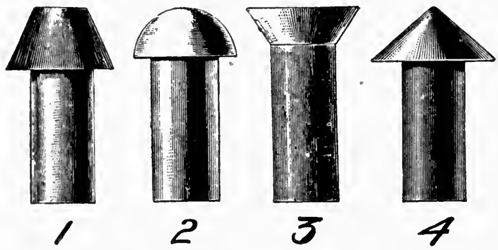


FIG. 244.—Types of Rivel Heads.

rivets for ship, bridge, boiler and tank work. They are designated as follows:

(1) Pan head.
(2) Button or round head.
(3) Countersunk.
(4) Cone or boiler head.

Rivet lengths do not include the head, except in the case of the countersunk rivet.

CHAPTER XIII.

OTHER SHOPS—SPECIAL PROCESSES.

395. Sheet Metal Work ·This is a subsidiary work in large building plants. It consists of making tanks, casings, large copper pipes, fenders, wheel guards, smoke and other conduits, and receptacles for oils and other materials. The heavier sheet-metal work is done in the boiler shop, where it is shaped by the equipment of that shop. The lighter sheet-metal work is shaped by hand appliances in the copper shop or sometimes in a separate sheet-metal shop.

Sheet metals are fastened together by riveting, soldering, or brazing. Seams in wrought iron or mild steel sheet work of moderate thickness may be readily and effectively welded by the oxy-acetylene blowpipe. Wiping a joint in plumbing work and sweating-on are forms of soldering.

By far the greater part of sheet-metal work is done in re-manufacturing processes such as were described in Chapter V. In plants which do this kind of work, large quantities of a particular article are made at minimum expense, and only special articles of certain shapes needed in small quantities are shaped by the expensive manual operations of the sheet-metal shop in a general building plant.

396. The Copper Shop. Materials Used.—There is usually considerable copper-pipe work to be done in a ship or engine-building plant. This is the principal work of the copper shop.

Copper is much used for small and medium-sized steam pipes which are subjected to moderate pressures, and for pipes to convey salt water and other liquids. This material is easily worked, is non-corrosive for all ordinary uses, and is particularly adopted for pipes which must have many crooks and bends to fit in confined spaces. Copper pipes often suffer in marine use from galvanic action, and tinning is much resorted to for protecting them.

The larger sizes of pipes are made of sheets of medium-hard rolled copper bent to cylindrical shape and brazed along the scarfed

edges. Copper pipe up to 8 inches in diameter is made from seamless-drawn copper tubing supplied from the tube mill. An assortment of this tubing is carried in stock in the copper shop.

Sheet copper comes from the rolling mill either thoroughly annealed as dead soft sheets dull in color, or of many degrees of hardness and springiness due to the pressure exerted by the rolls and to greater or less annealing after rolling. Planished sheet copper has a bright polished surface as a result of rolling without subsequent annealing.

FIG. 245.—Bench Shears.

The stock of material in the copper shop also includes more or less sheet brass of different thicknesses, degrees of hardness due to rolling, and of a composition suitable for shaping by bending and hammering cold.

397. Copper Shop Equipment.—This shop is equipped with various hand appliances for cutting, bending, hammering and riveting tubes and sheet metals; with small furnaces for brazing and annealing; and with apparatus for soldering.

FIG. 246.—Snips.

The shop equipment also includes, as does that of most other shops, squares, measuring rules, files, vises, compasses, cold chisels, metal saw, hand punches, wood mallets and scribers.

398. Cutting, Bending and Riveting Tools.—The principal tools for these uses are as follows:

(1) Bench shears. These are used for heavier cutting and are supported while in use by placing the bend of the lower handle in a square hole in the bench. See Fig. 245.

(2) Snips, or hand shears. Fig. 246.

(3) Forming machine. This is a small set of bending rolls used for bending sheets into cylindrical form as described in boiler-shop

work. These rolls are seldom longer than 3 feet, hence for bending longer sheets, a bending block is used, the end view of which is shown in Fig. 247. The solid iron mandrel *B* bends the sheet and the projecting edges are then beaten over it with wood mallets.

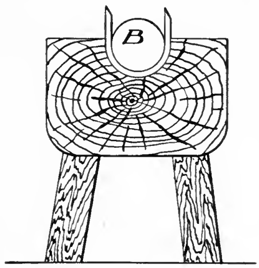


FIG. 247.—Bending Block.

(4) Tinners' stakes. These tools are anvils for sheet-metal workers. Fig. 248 shows a few of the many designs. They are supported in a square hole in the bench.

(5) Mandrels. These are long round bars of iron. One end is clamped down against the back edge of the bench top and the other

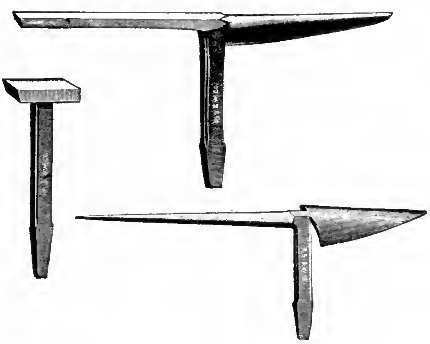


FIG. 248.—Tinners' Stakes.

end projects out horizontally two or more feet beyond the bench for use as an anvil in shaping work.

(6) Expanders. These are very similar to a boiler-tube expander. They are used to expand a copper pipe slightly for about 3 inches from the end for fitting two pipes together in a cup joint. An efficient expander may be easily made of a sleeve coupling (pipe-

fitting) screwed on the end of a short piece of iron pipe. This coupling is driven into the end of the pipe to be expanded.

(7) Drift set. This tool is shown in Fig. 249, No. 3, and is used to set the metal of the fillet *d*, Fig. 256, against the inner pipe to make a close-fitting joint preparatory to brazing the joint.

(8) Collar lifters. These tools (Nos. 1 and 2, Fig. 249) are used to enlarge a small hole drilled through the wall of a copper

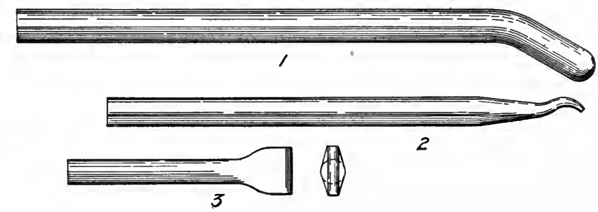


FIG. 249.—Coppersmith Tools.

pipe as an opening for a branch outlet. Their use is shown in Fig. 257.

(9) Burring machine. This machine is placed on the bench and operated by a crank. Its small disc rollers or "faces" turn a burr or flange on the end of a thin hollow cylinder, as a can end, and on the edge of a disc of metal to form a bottom.

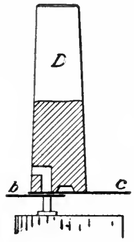


FIG. 250.—Rivet Set.

(10) Beading machine. This is another small portable bench machine. It rolls different designs of corrugations around the body of a pipe near the open end. These corrugations are usually seen as fancy rings on stove pipes or sheet-metal utensils, and they serve the purpose of stiffening the walls of the pipe.

(11) Rivet set. This set is used as shown in Fig. 250. The edges of two sheets of metal *b* and *c* are placed over the rivet as

shown. The set *D* is so placed that when struck with a hammer the rivet will punch a hole through the metal. The set is then shifted to place the small cone-head depression over the rivet end, and a blow of the hammer sets the end down to the form of the depression.

(12) Pipe bender. This machine is made in many forms by different makers. Fig. 251 shows a diagram of a machine adapted

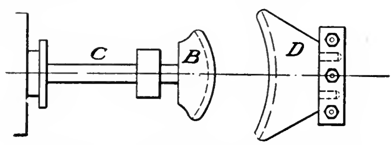


FIG. 251.—Pipe-Bending Machine.

to cold bending of wrought iron or other pipes up to 2-inch diameter when using steam or compressed air. A hydraulic machine can bend larger pipes. A die *B* is carried on the end of a piston rod *C*, and another die *D* rests solidly on the frame of the machine. The pipe is slowly bent as *B* travels toward *D*. The grooves in *B* and *D* must exactly fit the size of pipe to be bent to keep the pipe from flattening out of round as it bends.

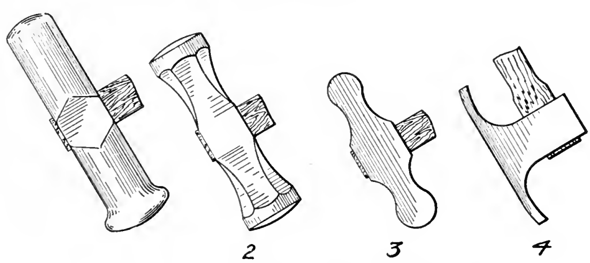


FIG. 252.—Coppersmith Hammers.

399. Coppersmith Hammers.—Fig. 252 shows the hammers made especially for coppersmiths' use. Their designations and uses are as follows:

(1) Raising hammer. Used to cup flat work.

(2) Planishing hammer. This has polished faces and is used to smooth the marks and wrinkles formed on pipes and other work during the operation of making them by hand.

(3) Collar hammer. Used to chamfer the edge of a sheet for making a lap joint, or for bell mouthing the end of a pipe.

(4) Spanking hammer. Used to smooth the surface of a straight pipe as it rests over a mandrel.

400. Brazing.—This is a process much used for uniting copper, brass or iron in a solid metallic joint of considerable strength, though the strength of the joint is not equal to that of the solid metal. The brazing material used, known as hard solder, spelter, or brazing metal, is variable in its composition. It may contain copper, zinc, tin, and silver, according to the melting point required and to the required strength of joint. The usual composition for brazing brass and copper is about 60% copper and 40% zinc. This alloy is melted together, and, after cooling it is heated to redness and broken into small lumps in a heavy mortar or on the anvil.

The essentials in brazing are (1) the metals to be brazed must be filed or scraped to a clean metallic surface and must be protected from becoming re-coated with oxide during the process by means of a flux, and (2) the metals to be joined together must have higher points of fusion than that of the brazing metal.

Brazing is accomplished by applying a considerable degree of heat to the parts to be brazed. This heat melts the brazing metal and allows it to run into the joint. The two parts to be brazed must be suitably held together by wires, tongs or clamps and the brazing metal must be so placed on the joint that gravity will cause it to flow into all parts of the joint when melted.

Borax, fused to drive off the water of crystalization and powdered when cold for applying it easily, is used as a flux. It may be mixed with the broken-up brazing metal if desired. If water of crystalization is not driven off, the borax swells and bubbles, causing more or less annoyance.

401. Heat for Brazing.—The necessary heat for brazing is usually supplied by a flat-topped forge or brazing table such as is shown in Fig. 253. This forge uses gas or oil fuel forced into the flame by compressed air. The air is necessary for the complete burning of the fuel to avoid a soot deposit on the work.

A forge table, similar to that shown, but with air-blast connection as in the blacksmith's forge, is much used for charcoal or coke fuel. This gives a less intense heat than gas or oil and is preferred

by many workmen for lighter brazing work. A blacksmith's forge with charcoal or coke fuel may be used for brazing.

A compound blowpipe with rubber-hose connections to gas and compressed-air supply is used as a portable heater where work cannot be brought to the furnace.

Small articles may be brazed by means of the mouth blow pipe, or may be heated in a charcoal fire without air blast.

Fig. 253.—Brazing Forge.

Some compositions of brass are difficult to braze because the zinc in them tends to melt out. Also they are usually very brittle when hot and must be handled carefully and allowed to rest quietly and free from air drafts until cool.

402. Annealing.—Copper and brass sheets are frequently shaped by hammering cold, as in shaping a hemispherical or other concave receptacle from a flat sheet, or in making bent copper pipes. The metal becomes more or less hard and brittle by hammering, and continued working would cause it to crack. At intervals during

the shaping, when the metal gets hard enough to produce a metallic ring, it must be annealed. This is done by heating it evenly on the brazing furnace and allowing it to cool. Copper may be cooled quickly by holding it in an air draft or plunging it into water, but it is safest to anneal brass of properties not thoroughly known by letting it cool slowly where it is free from air drafts.

403. Soldering.—This process of joining metals is much used by tinners and other sheet-metal workers for joints requiring but moderate strength. It is a simpler and more convenient process then brazing, as solder melts at a low temperature.

A soldering outfit consists of the following-named items:

(1) Soldering irons (more correctly called soldering coppers) as shown in Fig. 254. The lower copper is for heavy work.

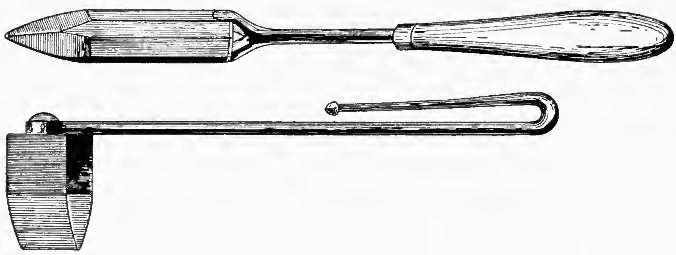


FIG. 254.—Soldering Coppers.

(2) Heater for soldering irons. This consists either of a small sheet-iron fire pot in which a fire of coke or charcoal is kept, or a gasoline torch with an attached rack for supporting the coppers in reach of the flame.

(3) Lead pans or cups for holding flux and acid to assist in soldering.

Solder, like spelter, varies in the proportions of its constituents according to the degree of hardness required, but the usual composition is 1 part lead and 1 part tin for tinners' work, or 2 parts lead and 1 part tin for plumbers' work. The ingredients of solders and spelters must be pure. Tinners' and plumbers' solder is designated as soft solder to distinguish it from hard solder for brazing.

404. Method of Soldering.—Two pieces of metal to be soldered together must be filed or scraped to a clean metallic surface if not

already bright. They are brought into the position in which they are to be soldered and firmly held together. The joint is sprinkled or swabbed with flux to remove grease and prevent the formation of oxide. Holding a bar of solder in one hand and a heated soldering copper in the other, the operator brings the copper against the bar, melting a slight amount of solder which either drips on the joint or sticks to the point of the copper by which it is wiped and spread over the joint. The two parts to be joined must be heated by the copper to the fusion point of the solder in order to make the molten solder stick to them.

A stronger joint may be made by first carefully tinning the surfaces joined in soldering.

The end of a soldering copper must be kept filed to a smooth point and this point is tinned with solder by rubbing it on a stick of solder. In heating the copper for use, it should not be heated enough to melt the solder from the point.

Soldering coppers heated by the electric current from an ordinary lamp socket are very convenient, dispensing with the use of the fire-pot.

Soldering fluxes remove grease and dirt, and assist in reducing or fusing the film of oxide covering the work. The usual fluxes are rosin, sal ammoniac, zinc chloride, and borax.

405. Copper Pipe.—This pipe is often made by the coppersmith from sheet copper, but it is better and cheaper to use lengths of seamless drawn pipe from the tube mill. The mill supplies pipe up to 8 inches, or possibly 10 inches in diameter. Larger pipes must be made from sheet copper.

A great advantage in the use of pipes made of copper is the safety and ease with which such pipes may be bent to suit the many crooks and turns necessitated by cramped machinery spaces. Thin-walled pipes (about No. 12 gage or thinner) are filled with melted rosin and heavier pipes are filled with dried sand to keep them from flattening when bent. A wood plug is driven in one end of the pipe, the entire length is filled with rosin or sand, and another plug is driven tightly in the other end. Rosin-filled pipes are bent cold and sand-filled pipes are bent hot. Bending is done in the hydraulic bending press, or by holding one end between two pegs or clamps

and pulling the other end with a block and tackle. A length of pipe may be slipped over each end of the pipe to be bent to assist in holding and in increasing the leverage of the pulling force.

Bending causes kinks or wrinkles to form at the inner curvature or throat of the pipe. These must be carefully hammered smooth while the pipe remains filled. The copper along the outer surface of curvature, or back, of the bend is necessarily thinned somewhat in bending, hence the practice of selecting a pipe with walls two or more gages thicker than is otherwise required.

Large pipes, or those of any size bent to a curve of small radius, are, in high-grade work, bent in two stages, *i. e.*, the pipe is filled

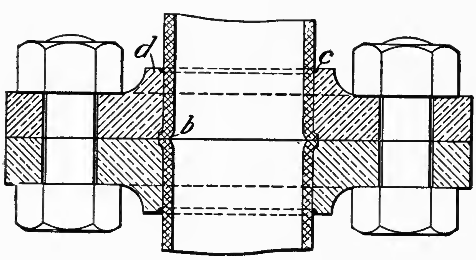


FIG. 255.

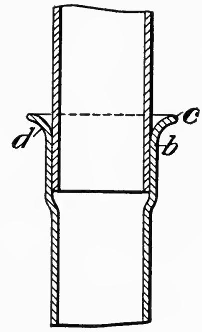


FIG. 256.

Copper Pipe Joints.

and bent part way to the required radius, is emptied, annealed, refilled and bent to the full extent required.

Small pipes may be bent, when filled, by means of the grooved formers shown in Fig. 251.

406. Joining Lengths of Copper Pipe.—One length of pipe may be joined to another by composition flanges as shown in Fig. 255 or in a permanently brazed cup joint as shown in Fig. 256.

The flange joint may be readily taken apart by removing the bolts. Flanges are standardized in all their dimensions and in composition. Each length of pipe is permanently connected to its flange by beading at the end, as at *b*, into a recess in the flange, and by brazing around the groove *c* made for holding the brazing

metal after it melts. A flange is brazed on while the pipe rests vertically, and frequently a ring of plastic fire clay is built around the joint on the flange shoulder *d* to keep the brazing metal on the joint while molten.

The lap of a cup joint is about equal to the diameter of the pipe. The cupped portion *b* is expanded by an expander, the bell-mouth *c* is flared by the collar hammer, and when the two lengths of pipe are cleaned for brazing and fitted together, the fillet *d* is closed against the inner pipe by the drift set. After brazing, the joint is smoothed by filing. The flared ring *c* assists to stiffen the pipe.

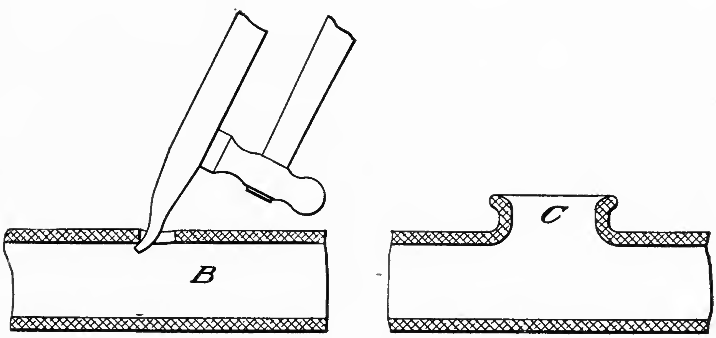


FIG. 257.—Preparing a Branch Joint Opening.

407. Brazing a Branch in a Copper Pipe.—To connect a branch to a length of pipe *B*, Fig. 257, drill a hole about $\frac{3}{8}$-inch in diameter in the pipe. Beginning with the small collar lifter, lift the edges of the hole carefully and evenly all around by strokes of the hammer on the under side of the lifter. When the hole is increased an inch or more in diameter, the larger lifter may be used. Care must be taken not to crack the metal by excessive expanding without annealing, nor by too much hammering at one place. When a collar is raised as shown at *C*, the edge is flared and a cup joint is formed for brazing.

Another type of branch joint may be made by cutting a hole in the pipe nearly the size of the desired outlet, lifting the edge as a slight collar, and placing over the outside of this collar the end of the branch. This end is suitably flared to lie snugly against the

outer surface of the pipe which it joins, forming a saddle flange which is brazed to the pipe.

A hole in a copper pipe may be stopped by brazing on a *flush* patch, which lies flush with the surface of the pipe, or by brazing on an *exposed* patch, which overlaps the outer surface of the pipe.

408. The Plate and Angle Shop.—Plates and structural shapes of mild steel used in ship building are cut and bent to shape in this shop, the principal equipment of which consists of:

(1) Power punches, used principally for punching rivet holes in ships' plates and frames.

(2) Power shears for trimming edges of plates, and for cutting lengths of angles, beams and other structural shapes.

(3) Plate-edge planer.

(4) Bending rolls.

(5) Garboard bending press (hydraulic) for bending plates cold to other than cylindrical form.

(6) Beam and angle bending or straightening machine.

(7) Bending slab and heating furnace.

Machines mentioned in items 1 to 4 inclusive are very similar to those for the same uses in the boiler shop. Particular shaped blades are used on shears for shearing structural shapes.

Much of the work of shaping ship material is done cold, except that of bending angles and other structural shapes on the bending slab.

Closely associated with the equipment of this shop are such tools as the portable hydraulic riveter, pneumatic riveters, chippers, drills and countersinks, used in the work of riveting together the frames and plates of the ship's hull.

409. The Bending Slab.—Fig. 258 shows a level floor of heavy cast-iron slabs used for bending angles and other structural shapes to various curved forms for ship frames. The slabs are well supported on permanent foundations, and the regularly spaced square holes in them are used to hold various pins and eccentric washers against which the frame is bent.

To arrange for bending, a wooden template giving the required curve of the frame is placed on the slabs and the curve is marked thereon with chalk. Pegs and washers are placed in the square holes along the chalk mark as guides against which the frame is

to be bent. An angle bar or other long piece to be bent is heated to a red heat in the long furnace shown in the background. The view shows the workmen in the act of dragging an angle from the furnace. This is dragged out, one end is secured between two pegs at one end of the curve outlined on the slabs, and the other end is dragged by suitable bars and other appliances against the guide pins and there clamped until cold. Very convenient clamps or dogs for this use consist of heavy round bars of iron bent into a flattened

FIG. 258.—Bending Slab and Heating Furnace.

V-shape, *i. e.,* with the two legs slightly less than 90° to each other. One leg is set in a slab hole and as the other comes against the work, a stroke of the hammer sets it tightly in a leaning position in the hole.

410. Special Processes.—A few special processes are outlined in the paragraphs which follow. These are selected because of the importance of their products or because of the application of the processes themselves to many different needs.

411. Malleableizing.—This is the process of rendering cast-iron castings malleable, or capable of bending without breaking. Castings

are not only relieved of brittleness, but a considerable degree of toughness and ductility is imparted to them. Many small articles of iron in every-day use, notably iron-pipe fittings, are far more readily made as castings and malleableized afterward, than if made of wrought iron or mild steel at the beginning. This process practically converts them into a mild steel by the removal of carbon, and its method of application is as follows:

Iron boxes of convenient size, known as annealing pots, are filled with castings, each of which is entirely surrounded by some kind of iron oxide, usually mill scale, squeezer scale, or pure magnetic ore. The castings have been thoroughly cleaned of sand and fins or other projections of metal before leaving the foundry, and a good sprinkling with sal ammoniac will give them a coating of rust, which as iron oxide, assists in malleableizing.

Each pot is closed with a thin iron cover luted with clay and may be placed in any kind of a furnace in which a steady heat may be maintained. In malleableizing works, several hundred post are stacked in a large furnace heated with producer gas. The brick-lined iron door of this furnace is closed, the contents are heated up to about 1800° in 24 hours, are maintained at this heat about 48 hours, and then allowed to cool gradually. At the high heat maintained, the castings give up their uncombined carbon to the oxygen of the iron oxide, and when removed they have lost the brittleness of cast iron.

This process is not so much in general use as formerly. Many castings are now displaced by drop forgings and articles of pressed sheet steel. These are neater looking and of less bulk than the usual run of malleable castings. Some shapes are cheapest made as castings, however.

412. Case Hardening.—This process is the reverse of malleableizing, *i. e.*, it adds carbon to forgings of wrought iron or mild steel to make them hard for resisting wear. Many articles, such as set screws, bolts and nuts, jaws of wrenches, etc., subject to unusual wear, are much increased in durability by case hardening after they are machined to shape. The process is as follows.

A number of forgings, each of which is surrounded by carbon substances such as ground bone and charred leather, are packed in an iron box. The box lid is luted with clay and the box is heated

gradually in a suitable furnace up to a temperature ranging from 1400° to 1700° F. This heat is maintained from 6 to 14 hours. The degree of heat applied depends upon the grade of steel in the forgings, and the duration of the heating depends upon the depth of the hardness required. The object of the process is to increase the amount of combined carbon in the forgings, as in the cementation process of steel making. The articles are removed from their boxes when cool enough to handle and are heated up to critical temperature and hardened by quenching in water or oil.

This process of hardening sometimes warps forgings slightly, a fault which may be in some cases very objectionable.

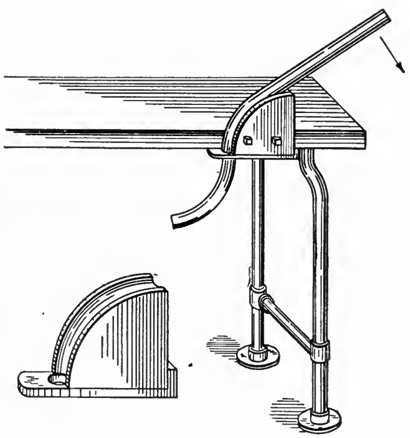


FIG. 259.—Form for Bending Small Pipes by Hand.

413. Pipe Bending.—Mention has been made in another paragraph of methods of bending copper pipes and small iron or brass pipes.

Two essentials in pipe bending are (1) to keep the pipe from flattening into elliptical shape in the bend, and (2) to avoid wrinkles in the concave part of the bend. These may be accomplished by bending the pipe over a grooved form shown in Fig. 259. The sides of the form may be extended well above the groove to hold the sides of the pipe against bulging along the bend. This form may be used for cold bending of pipes up to about $1\frac{1}{2}$-inch diameter.

A more elaborate form, suited to larger piping, is shown in Fig. 260. Large pipes should be heated red to facilitate bending.

A pipe may be filled with sand and plugged to assist in holding its circular cross section, and, if a bending form is not available, the jaws of a vise may be spread apart just far enough for the pipe to be held between them during bending. This will keep the pipe sides from bulging. The welded seam of a pipe should be in the throat or concave part of the bend.

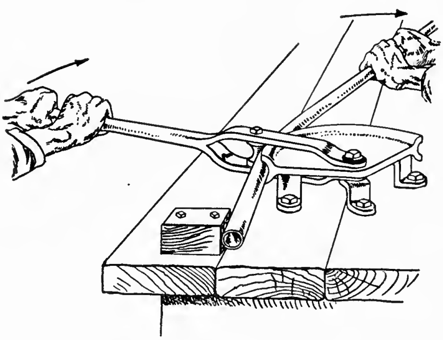


FIG. 260.—Form for Bending Large Pipes.

414. Joining Metals.—There are now in use many important means of uniting metals solidly together. These have many applications in manufacturing and one or more of them may frequently be availed of in making permanent repairs to broken machinery or equipment under emergency conditions.

Methods of joining metals include the following, some of which have been described:

(1) Soldering.
(2) Brazing.
(3) Welding at the forge.
(4) Electric welding.
(5) Thermit welding.
(6) Oxy-acetylene and oxy-hydrogen welding.
(7) Burning on.
(8) Puddling.

Closely akin to these methods is the use of metal cements, which stop cracks in castings, seams, and joints of patches held in place by aid of bolts and iron straps. A leaky pipe or boiler seam may often be stopped by the use of sal ammoniac and iron filings, or by a mixture of Portland cement and coal tar. A patented compound

known as Smooth On is very effective for mending broken machinery parts and repairing leaks in boilers, tanks and castings.

Joining metals implies an actual metal to metal contact. There is always an oxide or other coating over a metal surface exposed to air. This must be removed before two metals can be joined, and it is done principally by scraping, filing, pickling, etc. The last thin coating of oxide which forms during heating is removed by action of a flux. Union between the two metals is then accomplished (1) by bringing the contact surfaces of both metals up to the melting point of at least one of them, as in soldering and brazing, which necessitates the melting of the solder or brazing metal, or (2) by bringing both metals to a state of incipient fusion at the points where they are to be welded and pressing them together firmly.

There seems no doubt that the process of welding iron or steel detracts from their strength. The weld may not break under a tensile test, but the metal on one side of the weld may break instead. The high heating necessary for welding changes the grain size of iron and steel, making it coarse and thus weaker than before. This condition can be remedied by reheating welded bars to the critical point and in this way restoring the fine grain size, or in a measure by a thorough hammering while the weld is yet very hot.

415. Electric Welding.—When an electric current encounters resistance in its circuit a portion of its energy is converted into heat. If an electric current flows across the junction of two rods placed in mutual contact, more or less heat will be generated at this joint. If the joint does not present great resistance, a weak current will traverse it, and a large quantity of current will be required to generate enough heat to weld the rods together. If, however, the joint presents moderate resistance, due to the rod ends being more or less separated by air space, or by scale, sand, or other non-conductor, a stronger current is required to flow across the resistance, and a much less quantity of current will produce a welding heat.

Application is made of these conditions in electric welding operations. The first-named condition, that requiring the lesser strength of current is known as the *resistance* system, and the second con-

dition, requiring strong enough current to produce an electric arc, is called the *arc* system. In both systems the strength and quantity of current for welding depends upon the size of the weld and the time consumed in making it. The ordinary lighting circuit is strong enough for many needs in welding.

416. The Resistance System.—This system, developed by Prof. Elihu Thompson, is much used to weld together wires, rods, small forgings and other parts which are made separately for quick production. It is used in welding links of chains, rings, wire fence meshes, wheel tires, valves and their stems, lengths of steel steam pipe and their flanges, branch outlets, steam drums, etc. Different kinds of metal may be welded in one piece provided their melting points do not differ much.

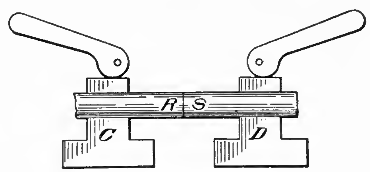


FIG. 261.—Electric Welding Clamps.

The essential features of the welding apparatus of this system are shown in Fig. 261. The pieces *R* and *S* to be joined are held firmly together in the desired relative position by heavy copper clamps *C* and *D*, one of which may be moved toward the other. Current travels along the circuit through *C*, *R*, *S* and *D*, and when the two ends *R* and *S* are softened by heat, they are mashed together by the pressure of the clamps, forming an expanded burr which is later cut off. In some machines, however, a swage surrounds the joint at the time of welding, avoiding the burr and pressing the metal together very firmly in a lateral direction.

Alternating current is required in this system of welding. It heats both sides of the joint more evenly.

417. The Arc System.—This system is used in repairing iron castings in a way which resembles soldering. A crack or cavity is filled up

with drops of cast iron or cast steel which melt from a rod as shown in Fig. 262. This view shows the method of filling a blowhole cavity in the end of the cast-iron mill-roll *R*. The upper end of the roll (shown in cross section) is surrounded by a piece of pressed coke *b* enclosed in moulding sand *c* held in a sheet-iron casing *d*. Enclosing the whole upper end of the roll is a mass of coke *k* surrounded by a checker-work *g* of fire bricks. This body of coke smoulders, keeping the roll hot during welding. A rod of cast iron *s* is clamped to the positive lead *p* of a direct-current conductor, and is manipulated by the insulated handle *h*. The negative lead *n* of the circuit is attached to the roll at a convenient point.

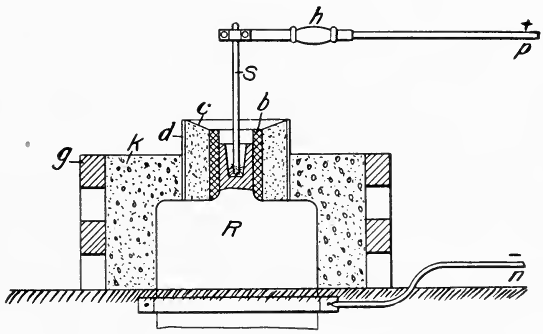


FIG. 262.—Arrangement for Arc Welding.

The lower end of the rod *s* is melted away by the arc, and is deposited in the cavity until the latter is filled.

418. The Thermit Process.—The essential feature of this process consists of generating, by chemical union between oxygen and aluminum, an intense local heat which produces from the reaction a certain amount of molten iron. This iron, which is in the nature of mild steel, may be run into a mould to form a small casting, or may be run between the two parts of a broken forging or steel casting to form a weld. The welding of cast iron by this process is very difficult because the heat of the process burns out the uncombined carbon of the casting, making it hard, brittle, and of uncertain strength.

Aluminum and oxygen have a very strong chemical affinity for each other. A mixture of finely ground aluminum and iron oxide

in proper chemical proportion, known by the trade name Thermit, will, when ignited, burn with an intense heat and release molten iron which may be used as stated. The chemical reaction is expressed by $Fe_2O_3+2Al=Al_2O_3+2Fe$. More iron than comes from the oxide may be supplied by placing iron punchings in the mixture before it is ignited, and the heat of the reaction will melt this iron and mix it with that formed from the iron oxide.

Ignition is accomplished by an ignition powder consisting of barium oxide mixed with powdered aluminum. A small quantity of this placed on top of a thermit charge and ignited with a match, will start the burning of the thermit.

This process is advantageously used in welding broken locomotive frames, spokes of heavy cast-steel wheels, ships' stern posts, rudder posts, propeller struts and breaks in other large forgings or steel castings, without removing them from their places. Its heat is also used in welding together lengths of heavy wrought iron or steel pipe. Lengths of street railway rails which are prevented by street paving from subsequent bending under expansion due to the sun's heat are smoothly and economically welded by this method. It is particularly suited to large work and is not economical for small work.

419. Making a Thermit Weld.—The simplicity of the equipment for thermit welding or casting makes it particularly valuable for work far removed from shop facilities. A quantity of thermit is placed in a conical, covered crucible as shown at *A* in Fig. 263. This crucible is made of sheet iron, magnesite lined, and the opening in the lower end is stopped by a pin resembling a long nail over which is placed a small disc of asbestos, a disc of iron and a little loose, refractory sand.

The ragged ends of the two broken parts to be welded are drilled or otherwise cut so that when in correct position there is a space of about $\frac{1}{2}$ inch between them. They are then clamped rigidly and the break is surrounded by a close-fitting mould made up of fire bricks and baked sand shapes of the required forms to afford openings as shown at *B* (Fig. 263) and to allow a collar of metal to be formed partially around the break in addition to the metal which fills it. All cracks in the mould must be carefully luted with fire clay to prevent the loss of metal through them.

The crucible is now suspended so that the opening is a few inches above the pouring gate. This completes the preparations.

The first step toward the actual welding operation consists of heating the ends of the broken parts to a red heat by directing the flame of a gasolene compressed-air torch through the heating gate of the mould. When this is done, quickly stop this gate with a dry sand core made for that use, and apply a match or burning splinter to the ignition powder on top of the crucible charge. The reaction which follows evolves heat and smoke but is not explosive. It ceases after a moment, leaving the crucible full of very hot molten mild steel which is tapped into the mould by a sharp upward knock on the pin end in the bottom of the crucible. A small quantity of slag (Al_2O_3) formed by the reaction floats on the metal.

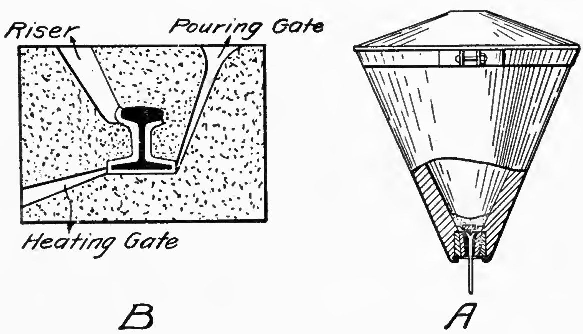


FIG. 263.—Moulds Crucible. Thermit Welding.

A mould may be made about a break by filling the break and the space for the metal collar with wax, around which is built an ordinary sand mould provided with the same openings shown in *B*, Fig. 263. This mould is contained in a sheet-iron box and the sand must be thoroughly dried. The wax is melted out when the torch is applied for heating before running the steel into the mould.

Thermit steel must run into a mould under the break and rise until the first metal, which chills in heating the mould, flows out over the top of the riser hole. This insures the thorough softening and joining of the broken parts with the molten steel which unites them.

After the weld has cooled, the mould is removed, the joint is smoothed up, and it is then annealed by maintaining a coke or charcoal fire all around it for 5 or 6 hours and allowing it to cool slowly.

420. Blow Pipe Welding.—The flame of a combustible gas may be so regulated in its shape and intensity by a properly constructed burner that it can be effectively used for local heating such as is needed in welding. In the compound blow pipe, a type of which is shown in Fig. 264, oxygen is admitted to one tube of the burner and a combustible gas is admitted to the other tube. These two gases pass along the channels 1 and 2, mix in the small receptacle 3, and finally pass from the nozzle at 4 where they enter the flame.

Oxygen is supplied from a steel cylinder in which it is stored under a pressure of 100 atmospheres or more, passing through a

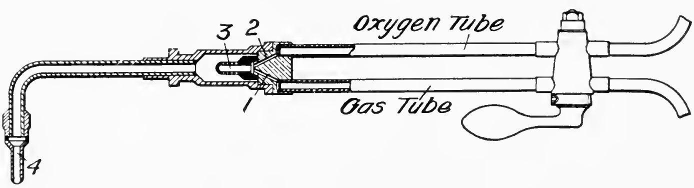


FIG. 264.—Compound Blow Pipe.

reducing valve which lowers the pressure to 30 pounds or less per square inch in the burner.

Hydrogen and acetylene gas are much used as the combustible gas. They may also be stored in steel cylinders as a convenient means of transporting them from the factories which make them, but acetylene gas is so easily produced that it is frequently made where it is used. Great care must be taken to avoid an explosion in using or handling any kind of inflammable gas. Acetylene is stored in steel cylinders with acetone, a liquid which absorbs a large volume of the gas under heavy pressure, thus avoiding the danger of this particular gas when compressed. In its simple process of production—that of admitting water to calcium carbide in a closed vessel—its explosive tendency is not always realized. A spark of flame coming in contact with the gas will cause an explosion in force and volume depending upon the amount of gas and oxygen or air in mutual contact.

As the mixture of oxygen and gas flows from the blow pipe, it burns in a flame which is regulated to suit the work to be done. The supply of each gas is so controlled by a small valve that the relative amounts and pressures of the two may be regulated as needed. The gas mixture should issue from the blow-pipe nozzle rapidly enough to keep the flame from following the mixture back into the pipe, and on the other hand the flame should not receive too strong a blast by too rapid a flow of gas. The quantity of oxygen must be kept down enough to avoid an oxidizing flame in welding.

Slightly different forms of blow pipes, determined by experiment, are necessary for burning gases under different pressures and different intensities of flame, according to the requirements outlined in the preceding statements.

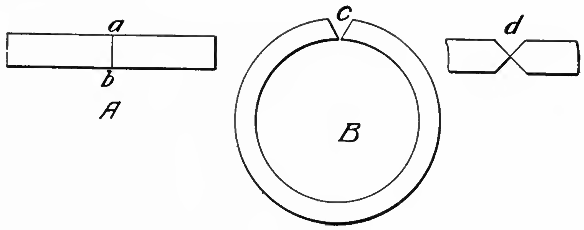


FIG. 265.—Methods of Welding Plate Edges.

421. Method of Making a Blow Pipe Weld.—The ease with which an oxy-acetylene or an oxy-hydrogen outfit may be set up where needed, and the small size of the blow pipe and its flexible rubber-hose connections, make such an outfit very practical and convenient for use on work which demands local heating.

In making a weld, two sheets of metal are butted edge to edge in a clean, close-fitting joint as shown at *A*, Fig. 265. Two blow-pipe flames are held at *a* and *b* on opposite sides of the plates, directly opposite each other, and a short length along the seam is heated to welding heat. With one of the pieces properly supported to hold it firmly in place, the other may be struck with a hammer to bring about the weld through the closer contact due to the blow.

Another method of welding is shown at *B*, Fig. 265. A sheet of metal rolled to cylindrical form presents its edges in V-shape as at *c*. These edges are temporarily held together by bolts and straps.

A blow-pipe flame is directed into the joint to bring it to welding heat, and at the same time a heavy wire of pure Norway iron is held so that the flame melts its end. The drops of fused metal from the wire run into and fill the joint, resembling the process of soldering, until the entire notch is filled with solid metal. The joint should be hammered while hot to restore the grain size of the fused metal and increase its strength. The joint needs no particular cleaning nor any flux before welding is begun.

A thicker sheet of metal may be cut at the edges to form a joint as at *d,* and is welded along the upper notch and then rolled half-way around and welded along the lower notch.

A poor joint will result if the operator allows drops of metal to fall upon a part of the seam not heated to welding temperature.

422. Application of Blow-Pipe Welding.—This method is much used to join the edges of wrought iron or steel plates up to an inch or more in thickness. Heavy plates conduct away the heat so rapidly that it may not be possible for the burner to raise the seam to welding temperature. Steel castings may also be welded, and cracks or blow holes may be filled with drops of molten iron. Brass castings may be repaired by melting into a crack, cavity or blow hole, drops of brass from a rod of the same composition as the casting.

The difficulty of welding iron is in proportion to the amount of carbon it contains, and, while some operators claim ability to weld or mend cast iron, it is difficult to do so. A cast-iron bar may be fused at the end into drops which will weld to a properly heated cast-iron surface, but the iron will not be homogeneous and it may be too brittle for strength and too hard for machining.

Aluminum may be welded, under blow-pipe heat, by use of a flux which removes the oxide, although this metal cannot be soldered or brazed, at least by usual means.

Steel pipes and flanges may be welded together, and lengths or branches welded in one piece.

A particular application of gas welding is that used in welding the longitudinal seam of a boiler drum made of one sheet of metal. The drum is mounted on a machine especially built to handle it readily and quickly. The machine carries two specially constructed

burners which travel along on opposite sides of the lapped plate edges, heating them to welding heat. The burners are followed by rollers which exert great enough pressure to make the weld and to press the seam down to the thickness of the plate. Water gas and air are used in the burners. The strength of such a welded joint is about 90 or 95% that of the solid plate, although the ordinary oxy-acetylene-welded joint is not over about 80 or 85% of the plate strength.

423. Blow-Pipe Cutting of Metals.—A remarkable method of cutting metals has been developed in the use of the oxy-hydrogen and oxy-acetylene burners.

To a blow pipe used for heating is attached an additional tube through which a jet of oxygen is blown from a supply tank. The blow-pipe flame heats the metal to be cut, and when so heated, the small jet of oxygen directed against it burns a narrow cut along any path over which the flame may be directed. So readily do oxygen and red-hot metals unite, that such a burner is used to cut plates of metals, including steel armor, up to 9 inches thick. The width of the cut is not over $\frac{1}{8}$ inch and the metal on each side of the cut is unchanged in grain size or otherwise. Tubes, shafts, and structural shapes may be easily and quickly cut by this means, although there is difficulty in cutting cast iron due apparently to the carbon it contains. Rivet heads are quickly cut off without marring the riveted plates, and any tangled mass of iron or steel wreckage, old boilers, or the hull of a ship may be easily cut to pieces by this method. In cutting a hole of several inches diameter in a steel plate, a small hole is first drilled to give the burner a start.

Hydrogen is more effective for this cutting than is acetylene, as the former makes a hotter flame. For light cutting, a blow pipe may be used which has no extra oxygen tube attached. The flame is given an excess of oxygen from the regular tube, making it an oxidizing flame.

424. Burning On.—This is a method employed for mending a cracked, broken, or honey-combed casting of cast-iron or brass. Many costly castings which would otherwise have to be discarded may be made sound by this process, although defects in some cases are too extensive, or are not well located for practical repairing.

The application of the method is illustrated in Fig. 266. The view *A* shows the casting to be repaired and *B* shows the same casting bedded in sand and otherwise prepared for the work. Let it be supposed that the portion *b* of the upper flange of *A* is cracked or filled with blow holes. The defect is chipped out to present a slit or cavity which shows sound metal. Supporting the casting firmly on the foundry floor, surround the defective part with a mould made of baked sand cores and fire bricks wedged and clamped in place. The joints between bricks and cores are carefully plastered with clay. It is essential to leave either a small hole *c* leading from the bottom of the mould, or one at *d* leading from the highest point at which the metal is to stand in the mould. Both openings may be

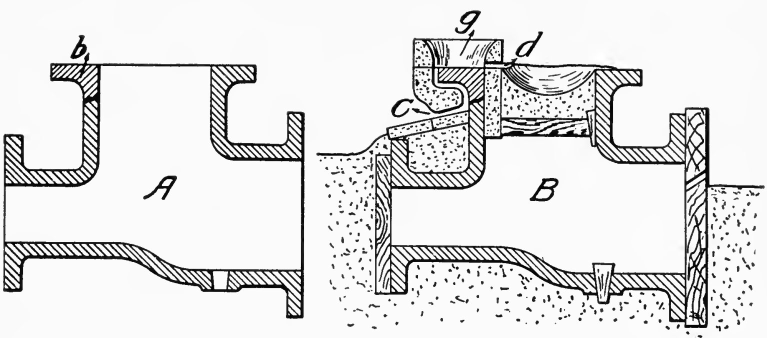


FIG. 266.—Mending a Casting.

provided if desired, and each leads into a sand basin which holds metal as it flows from the mould. After assembling and securing the mould around the defect, the casting must be heated by means of a gasolene torch or blow pipe. This heating may be slowly done by using a charcoal fire, and sometimes the position of the defect is such that heating must be done before the mould parts are placed. When the casting is nearly or quite red hot, a ladle of molten metal of the same composition as the casting is held over the opening *g* in the upper core, and a steady stream is poured into the mould, keeping it filled. The first metal poured in serves merely to heat and soften the metal around the defect, and is allowed to flow out. The stream of molten metal is continued until it has about melted the metal adjacent to the defect. A small iron rod is used to deter-

mine this condition. The lower open c is then stopped with a shovel full of dry earth, and the mould is left full of metal. The casting is covered with a few pieces of sheet iron and allowed to cool slowly. When cool, the defect will be found filled with solid metal which can be trimmed to the contour of the casting.

Cast iron may be brazed by means of spelter as described for brazing copper. It is essential (1) that the broken parts be thoroughly free of scale, dirt and grease; (2) that they be clamped in their correct relative position; (3) that heating be done evenly in a clean fire, and (4) that the spelter be applied along every part of the break.

425. Puddling.—This is a method of repairing small broken castings similar to burning on. A mould of clay or plaster of Paris is formed about the broken parts of a small casting as shown at b,

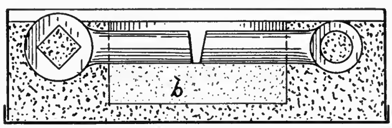


FIG. 267.—Uniting a Broken Casting.

Fig. 267. When dry, the mould holds the casting firmly. Both are supported in a box of sand, and the fracture is heated with an oxy-hydrogen or an oxy-acetylene blow pipe. At the same time a rod of metal is held in the flame so that the end melts and joins the highly heated ends of the casting. These ends are kept practically molten until enough metal has melted from the rod to join them together.

After the casting has cooled, the superfluous metal is ground away. This method of mending castings burns out the carbon of cast iron and makes the joint harder and more brittle than the iron of the casting.

426. Classification of Welding Methods.—Those methods which accomplish the union of two pieces of metal directly by fusion of one to the other, without the intervention of another metal at the joint, are classed as *autogenous* methods. Those which accomplish union between two metals by means of an intermediate metal, as in soldering and brazing, are classed as *heterogeneous* methods.

427. Grinding.—The popular idea of grinding is its use in shaping more or less roughly the edges of cutting tools and in removing fins and other small projections from forgings and castings as a step toward making them smooth.

Developments in recent years in the production of grinding wheels of many shapes and degrees of hardness and the fitting of these wheels to high-grade machines for controlling their motions, have brought into practical use methods of grinding which produce smooth and true surfaces of a degree of accuracy not attainable by any other known means.

Work is now roughed out on the lathe, planer, milling machine and other machine tools and is finished to any desired degree of accuracy better, cheaper and quicker by grinding machines than by other means. This applies to the ordinary as well as to the finest finishing, and it applies also to metals of all degrees of hardness.

428. Grinding Machines.—Machines for accurate grinding are usually built on the general lines of either a lathe or a milling machine. In these machines, the grinding wheel takes the place of the cutting tool, and it is so mounted that it can be revolved at high speeds suited to the work.

The grinding lathe holds work between centers, or in special chucks, and the wheel may be fed along the lathe bed as it revolves in light contact with the cylindrical work to be ground. This machine is used for grinding engine valve stems, piston rods, and any similar cylindrical work. Crank shafts of automobile or other small engines are finished from the rough forging in this machine.

The milling machine form of grinder may be either a plain or a universal machine. Work may be placed on its movable table for flat grinding, or the usual lathe center attachments may be used to support work for internal and external cylindrical or other curved-surface grinding. In these machines, the rapidly revolving grinding wheel takes place of the milling cutter. These machines are used for grinding drills, milling cutters, cams, parts of many articles made in quantity such as guns, pistols, tools, and an endless variety of small castings and forgings requiring machine finishing.

The spindle which carries a grinding wheel and the bearings in

which it rests are made with the greatest accuracy possible and are fitted to allow no play whatever between spindle and bearing. Grinding may be either wet or dry, but wet grinding is the more accurate as it prevents inaccuracy due to change in temperature of the piece operated on. The machine must be amply protected from water and grit in wet grinding or from dry grit in dry grinding.

429. Grinding Wheels.—Experience has shown that the kind of wheel, its periphery speed, the extent of contact between the wheel and the work, and the rate of feed of the wheel over the work are essential factors in successful grinding.

The kind of wheel depends upon three factors, viz., (1) the grinding material of which the wheel is made; (2) the size of grains of this material, and (3) the strength of the cement bond holding the grains together. Wheels are made of *emery,* one of the many forms of aluminum oxide found in nature; *corundum,* an artificially made aluminum oxide much purer than emery; and *carborundum,* a compound of silicon and carbon. Corundum and carborundum are products of the electric furnace. These materials are crushed to powder, and the grains are separated according to their sizes. A wheel is made up by mixing grains of a certain size with a bonding material. Hydraulic cement is much used for bonding high-grade wheels. The wet mixture of cement and grinding material is moulded to shape and burned into a bonded mass in a furnace at high temperature. In operation, the wheel cuts by contact of the sharp hard particles against the material operated on, and as these particles become dull, they gradually crumble away from the bonding material and give place to sharper particles. The softness or hardness of a wheel depends upon the strength of the bonding cement.

Makers of wheels and of grinding machines supply full information of the proper kind, size and speed of wheel for each class of use.

Wheel surfaces are trued by a diamond-pointed tool held against the wheel as it revolves.

430. Lapping.—This is a method of grinding external and internal cylindrical surfaces to a finer degree of accuracy ($\frac{1}{10000}$ inch) than can be obtained with certainty in the use of a grinding wheel. It is under more certain control and is employed to finish wheel-

ground work when the highest attainable degree of accuracy is required.

The process consists of revolving the work in a grinding lathe while it is lightly held in a lead-lined clamp on which is smeared a thin coating of oil and very fine grains of grinding material. For internal grinding, a lead-covered iron plug, or a plug with lead ribs cast in longitudinal grooves, is used to carry the grinding material. The hard grains of grinding material become unbedded in the soft lead and their grinding action is guided by the contact of the lead itself with the surface to be ground.

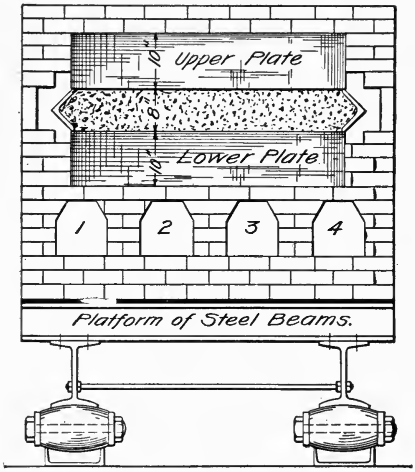


FIG. 268.—Armor Plate Hardening.

431. Armor-Plate Making.—An armor plate should be hard enough on the outer surface to prevent penetration by a shell and tough enough under the hard surface to resist breaking or cracking. Armor plate is commonly made of nickel-steel with which is alloyed chromium, tungsten, or vanadium. Nickel increases toughness and the other metal increases hardness.

Armor steel is made from high-grade ore by either the acid or the basic open-hearth process. The reduction of phosphorus in the steel is highly essential, hence the basic process is employed in America. The ingot is cast in a very large cast-iron mould lined inside with a layer of hard-baked loam. It is forged to shape under

a powerful hydraulic forging press, is planed to dimensions, and is then subjected to the hardening process.

Fig. 268 shows the diagram of two plates prepared for hardening. A heavy steel car is covered with layers of fire brick to protect it from intense heat, and on this is built the structure shown. The flues 1, 2, 3, 4 allow the passage of hot gases under the lower plate. Between the two plates is a layer of powdered charcoal. The car supporting this structure is rolled into a regenerative furnace and is walled in. It is then heated up gradually and kept above a red heat for several days. The carbon penetrates the steel, as in the cementation process, and the degree of penetration depends upon the degree of heat and upon the length of time the heat is maintained. It is estimated that the process occupies five days for heating and cooling and one day for each inch of penetration of the carbon. As carbon is absorbed, the angle iron frame gives down under the weight of the upper plate and allows this plate to remain it contact with the carbon.

The plates are hardened after removing and cleaning. This is done by reheating and spraying the carburized surfaces with jets of cold water. This hardness penetrates only about 2 inches or less, but the surface is so hard that it cannot be cut or drilled.

The processes of armor making are guarded with much secrecy by the few manufacturers who are engaged in this work.

APPENDIX

432. Table of Brasses and Bronzes.—The following table gives a list of the brasses and bronzes in common use. Their compositions as here given are more or less varied by manufacturers.

The skill of melters, and their personal experience, lead them to good results on alloys with mixtures not exactly the same in relative amounts.

TABLE OF BRASSES AND BRONZES FOR ENGINEERING USE.

Name.	% Copper.	% Tin.	% Zinc.	% Lead.	% Aluminum.	% Iron.	% Phosphorus.	% Manganese.	Elastic Limit, lbs.	Tensile strength lbs.	Uses.
Muntz Metal.	60	....	40	....	....	....	....	....	....	35,000	Bolts and nuts. Sheathing for wooden hulls of ships.
Cast Naval Brass.	61 to 63	1 to 1.5	Remainder.	....	....	....	....	....	....	....	Castings in which great strength is not required.
* Rolled Naval Brass.	do	do	do	....	....	....	....	....	30,000	60,000	Bolts for propeller blades, air pumps, condenser heads. Valve stems.
Rolled Sheet Brass.	60 to 70	....	40 to 30	.5	....	....	....	....	....	....	The grades are "soft," "medium hard," "hard," "spring." Must stand bending through 180° without fracture on inner radius equal to thickness of material.
Seamless Brass Pipe.	do	....	do	do	....	....	....	....	....	....	For steam and water piping. Standard sizes.
Brazing Metal.	84 to 86	....	16 to 14	....	....	....	....	....	....	....	Brazing metal and all flanges and fittings held by brazing.
Gun Bronze.	87 to 89	11 to 9	Remainder.	....	....	....	....	....	....	....	Brass valves and fittings requiring great strength.
Journal Bronze.	82 to 84	12.5 to 14.5	2.5 to 4.5	....	....	....	....	....	....	....	Bearings, slides, and other parts subjected to friction.
* Phosphor Bronze.	87	10	2.3	....	....	....	.7	....	....	....	Pump rods, valve springs etc., exposed to salt water.
* Cast Manganese Bronze.	56	3/4	41 3/8	....	1/2	1 1/4	....	1/8	30,000	60,000	Propeller hubs, blades, engine framing, composition castings requiring great strength.
* Rolled Tobin Bronze.	59	2.16	38.40	.31	....	.11	....	....	....	....	Propeller blade bolts and other bolts of composition requiring great strength.
* Aluminum Bronze.	99 to 90	....	....	....	1 to 10	....	....	....	....	70,000 to 100,000	Non-corrosive forgings or castings requiring great strength.

* Must stand forging at red heat and bending cold.

433. Degrees of Hardness of Steel Tools.—The amount of carbon in various well-known tools and implements made of hardened steel is shown approximately by the following list:

.6 to .7 per cent.	.7 to .8 per cent.	.8 to .9 per cent.	.9 to 1.0 per cent.
Screw drivers.	Smiths' hammers.	Wrenches.	Machinists' hammers.
Anvil tools.	Punches for metals.	Circular saws.	Hand saws.
Gun barrels.	Hand picks.	Lathe centers.	Cold chisels.
Chisels for hot metals.	Wood augers.	Anvil facing.	Steel springs for Vehicles.
		Vise jaws.	
		Drop-forging dies.	

1.1 to 1.2 per cent.	1.20 to 1.25 per cent.	1.25 to 1.30 per cent.	1.30 to 1.50 per cent.
Rock drills.	Pocket knives.	Ball bearings.	Saws for cutting steel.
Threading taps and dies.	Wood chisels.	Strong magnets.	Tools for cutting hard metals.
Lathe tools.	Hatchets, axes.	Files.	Metal scrapers.
Steel springs for power.	Twist drills.	Wire-drawing dies.	
	Pipe cutters.	Glass-cutters.	
	Milling cutters.		
	Cutters for wood-working machines.		

Degree of Hardness.	Per cent of carbon.
Very hard	1.50
Hard	1.25
Medium hard	1.00
Tough	.80
Tenacious	.65
Very elastic	.30

434. File Making.—To illustrate many of the essential operations in making tools, a description of file making is here given. This description applies to a flat tapered file of rectangular cross section. The steel used is a superior grade of high-carbon crucible

steel, received from the manufacturers in bars about 12 feet long and of the same cross section as the file. The steps are as follows:

(1) *Forging.*—A bar is cut into blanks of the length required. Each blank is heated, the tang or handle end is forged by a rapidly working machine hammer, and the taper end is forged by hand.

(2) *Annealing.*—As the blanks cool, they become somewhat hardened and must be softened by annealing. Several forged blanks are packed in a bulky cast-iron box, and its lid is placed on and luted with clay. Small blanks lose some carbon in heating for forging, and this is restored by packing carbon around the blanks to be annealed. The cast-iron boxes and contents are heated gradually in a furnace to red heat and allowed to cool slowly, occupying two or three days.

(3) *Straightening.*—When annealed, the blanks are inspected by a man who straightens crooked blanks by tapping with a hammer.

(4) *Grinding and Drawfiling.*—Straightened blanks are ground on large grind stones to remove scale and expose a clean metal surface. Some blanks are so ground as to remove entirely any decarburized surface due to heating before forging. The grinding is in some cases supplemented by filing the blanks to make them level across their length, as the stones cannot grind a true flat surface.

(5) *Cutting.*—The teeth are then cut on the blanks in a machine. A blank lies flat on the lead-covered machine table and is fed in the direction of its length under a wide chisel which is held by the machine and made to oscillate rapidly in a vertical direction or in a direction slightly inclined to the vertical. This chisel strikes the blank and cuts a gash entirely across its width. A double-cut file is run under this chisel twice before the opposite side of the blank is cut. A rasp file is cut by a small chisel resembling a punch which strikes the blank at an angle and raises teeth from its surface. If the blank is bent in cutting the teeth, it is straightened by a lead hammer. This is seldom necessary.

(6) *Dipping.*—After cutting, the files are usually stamped with the name of the makers, and are then prepared for hardening by dipping into a mixture which forms a film over the surface and prevents oxidation of the tooth points as the file is passed from the heating to the hardening bath. If necessary, this dipping is preceded by a bath of strong alkali to remove grease.

(7) *Heating and Hardening.*—Each pile is then heated gradually by dipping it into a molten-lead bath kept at a uniform high-temperature by oil burners. It is hardened and tempered in one operation by quenching in salt water.

(8) *Cleaning.*—After hardening, each file is cleaned by scrubbing, and is further relieved of dirt and clinging particles of metal by subjecting it for a moment to a blast of fine sand and water. This renders the teeth clean and sharp.

(9) *Softening Tangs.*—The tang ends (handle ends) are then softened by heating in lead and cooling in oil. This keeps the tang from breaking when in use.

(10) *Final Inspection—Testing.*—Each file is now carefully examined for defects in manufacture, and if perfect, is oiled to prevent rusting. It is then struck on an anvil to detect from the sound any possible flaw, and is tried in filing a piece of metal of standard hardness to discover if it has the right hardness. If these tests are passed, the file is brushed and sent to the packing and shipping department.

435. Wire Gage Table.—The following table is given to show a comparison of the various wire gage systems:

Wire Gage Units.	Actual Dimensions in Fractions of an Inch.				
	1 American or Brown & Sharpe.	2 Birmingham Wire Gage or Stubb's Iron.	3 Stubb's Steel Wire.	4 U. S. Standard for Steel and Iron Plates.	5 British Imperial Standard Wire Gage. (S. W. G.)
0000	.4600	.454	....	.406	.400
000	.40964	.425	....	.375	.372
00	.3648	.38	....	.344	.348
0	.32486	.34	....	.313	.324
1	.2893	.30	.227	.281	.300
2	.25763	.284	.219	.266	.276
3	.22942	.259	.212	.250	.252
4	.20431	.238	.207	.234	.232
5	.18194	.22	.204	.219	.212
10	.10189	.134	.191	.141	.128
20	.03196	.035	.161	.0375	.036
30	.01002	.012	.127	.0125	.0124
40	.00314	....	.097	.....	.0048
50	......	....	.069	.....	.001

Intermediate sizes above No. 5 are not here given.

436. Wire Dies.—Wire dies are usually made of chilled white cast iron, hard-carbon steel, and alloy steel. The very smallest sizes of dies are made of diamonds because drawing soon enlarges a very small hole in a steel die.

Sometimes a coil of wire is found in the market which is not of the same size throughout. This may be due to running the drawing block too fast, which stretches the wire in soft places after it has passed through the die, or it may be due to the wearing of the die. When it is essential that a coil of wire be of the same diameter at both ends, it is drawn nearly to gage in a roughing die and is finished in another die which has little work to do.

As diamond is the hardest substance known, it requires special means and considerable time to get a hole in a diamond die. An uncut gem, somewhat flat and round, is mounted in a piece of soft metal and is firmly secured in a small machine much resembling an ordinary sewing machine. The oscillating arm of this machine carries a small hard steel point, just as a needle is carried in a sewing machine, and the arm is adjusted to make this point strike the diamond surface just at the end of the oscillation. The point strikes the diamond several hundred times a minute and a cutting action is obtained by covering the gem with diamond dust held in place by oil. The steel point is revolved as it oscillates, and it is so worn at the end of 10 or 15 minutes that it is replaced by another point. It requires a week or more to cut a very small hole in the diamond. Steel points are ground round by holding them against a diamond chuck revolved rapidly by a small lathe.

437. Dimensions of Standard Iron Pipes.—The following table shows the standard dimensions of iron pipe, including standard threads for ends of the pipe. These standard sizes are made in wrought iron, mild steel, and brass as commercial products.

In ordering iron pipe it is necessary to designate only the size of pipe required as given in the first column of the table, without any mention of thickness.

Size Inches.	Actual Outside Diameter Inches.	Thickness Inches.	Threads per Inch.	Size Inches.	Actual Outside Diameter Inches.	Thickness Inches.	Threads per Inch.
1/8	.405	.068	27	3½	4.0	.226	8
1/4	.54	.088	18	4	4.5	.237	8
3/8	.675	.091	18	4½	5.0	.246	8
1/2	.84	.109	14	5	5.563	.259	8
3/4	1.05	.113	14	6	6.625	.280	8
1	1.315	.134	11½	7	7.625	.301	8
1¼	1.66	.140	11½	8	8.625	.322	8
1½	1.9	.145	11½	9	9.625	.344	8
2	2.375	.154	11½	10	10.75	.366	8
2½	2.875	.204	8	11	11.75	.375	8
3	3.5	.217	8	12	12.75	.375	8

438. Methods of Threading Bolts.—Bolts are usually threaded by being held firmly in a machine which runs a briskly revolving threading die along the body of the bolt as far as the thread is to extend. These dies are kept deluged with oil while they work, though the work is so severe that they wear out rapidly.

A very effective thread for the cheaper-made bolts is either cold or hot pressed on the bolt by a machine, the essential principle of which is shown in Fig. 269. The bolt B is placed between the flat

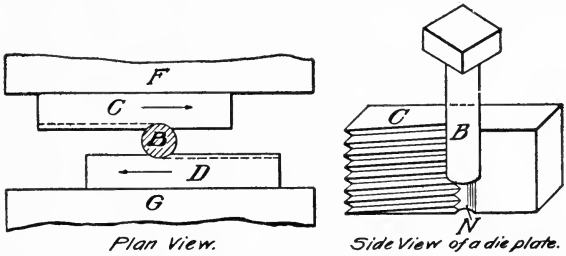


FIG. 269.—Dies for Rolling Threads on Bolt Ends.

dies C and D which are made to move in the direction of the arrows and are held firmly at a given distance apart by bearing against the parallel faces of the guides F and G. Each die moves forward and back once, traveling a distance in one direction equal to at least the circumference of the bolt.

The side view of the die plate shows how it is cut to impress threads on the bolt. The notch N is cut in the face of the die to the depth of the threads.

439. Illustration of Automatic Screw Machine Work.—Fig. 270 shows the steps in the work of cutting the small helical gear wheel shown at *W* in Fig. 92, Chap. VI. This is done in six operations, requiring a total of 80 seconds of time. A dimension drawing of the wheel is shown at the bottom of the illustration. Operation IV, that of cutting the spiral teeth, is done by a very ingenious tool made up of several moving parts, all automatically operated, and designed at the works of The Brown & Sharpe Mfg. Co., Providence, R. I.

440. Shop Location and Equipment.—In locating and equipping a manufacturing plant the following-named factors are of importance:

(1) The cost of obtaining raw materials at their source of supply, their quality and the available quantity.

(2) Cost of transporting raw materials to the plant and finished products to market.

(3) Cost of fuel for manufacturing.

(4) Cost and available supply of labor needed.

(5) All buildings should be well lighted, dry and comfortable and convenient for workmen.

(6) The power house (boilers, engines, and electric generators) should be located convenient for receiving fuel and for distributing power to the shops needing it.

(7) The buildings should be so located with reference to one another as to afford a short and ready means of transferring work from one shop to another in regular course of construction.

(8) Appliances for lifting and carrying heavy work readily in the shops should be installed, and the machines in each shop should be placed to reduce necessary handling of heavy work to a minimum.

From the receiving of raw materials at a plant until they leave as finished products, they are handled many times. It saves time, labor, and cost to reduce this handling to a minimum, and careful study should be made with the view of eliminating all unnecessary handling. Much unnecessary handling and many needless movements of workmen are many times overlooked because they are a part of custom or habit. These points are given careful attention in progressive shops.

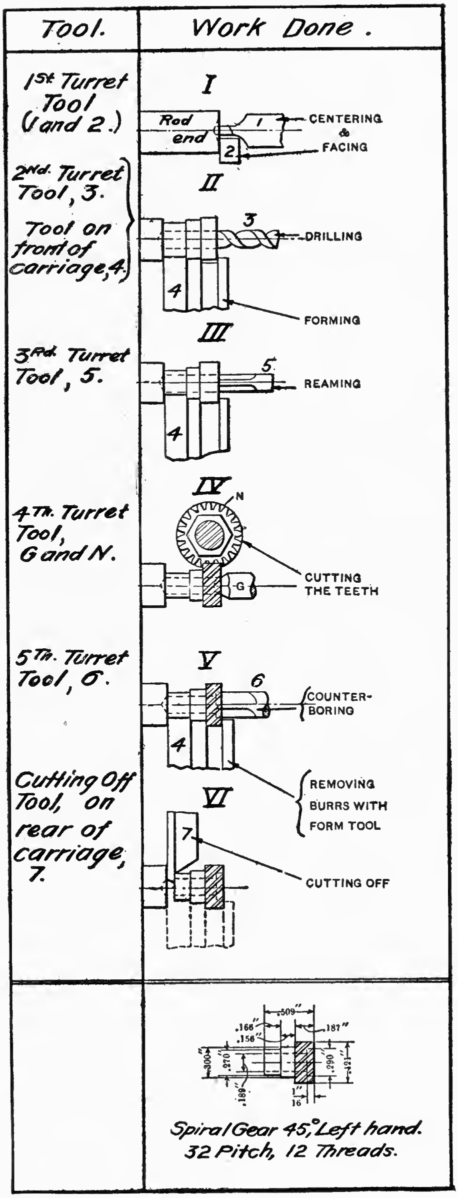


FIG. 270.—Specimen Operation of Automatic Screw Machine.

441. Allowance for Forcing and Shrinkage Fits.—A table is here given, showing the usual allowance or difference, in fractions of an inch, between a shaft and the hole in which it fits, for forcing and shrinkage fits.

Shrinkage fits.		Forcing fits.		
Diameter in inches.	Allowance (or difference in diameters).	Diameter in inches.	Minimum allowance.	Maximum allowance.
2	.0025	2	.003	.005
8	.0090	8	.009	.011
16	.0175	16	.014	.017
40	.0400			
65	.0700			

442. U. S. Standard Screw Threads.

Diameter of screw.	Threads per inch.	Diameter at root of thread.	Diameter of screw.	Threads per inch.	Diameter at root of thread.
1/4	20	.185	2	4 1/2	1.7113
5/16	18	.2403	2 1/4	4 1/2	1.9613
3/8	16	.2936	2 1/2	4	2.1752
7/16	14	.3447	2 3/4	4	2.4252
1/2	13	.4001	3	3 1/2	2.6288
9/16	12	.4542	3 1/4	3 1/2	2.8788
5/8	11	.5069	3 1/2	3 1/4	3.1003
3/4	10	.6201	3 3/4	3	3.3170
7/8	9	.7307	4	3	3.5670
1	8	.8376	4 1/4	2 7/8	3.7982
1 1/8	7	.9394	4 1/2	2 3/4	4.0276
1 1/4	7	1.0644	4 3/4	2 5/8	4.2551
1 3/8	6	1.1585	5	2 1/2	4.4804
1 1/2	6	1.2835	5 1/4	2 1/2	4.7304
1 5/8	5 1/2	1.3888	5 1/2	2 3/8	4.9530
1 3/4	5	1.4902	5 3/4	2 3/8	5.2030
1 7/8	5	1.6152	6	2 1/4	5.4226

443. Hydraulic Data.

TABLE OF GALLONS.

	Cu. ins. in a gallon.	Wt. of gal., pounds avoirdupois.	Gallons in a cu. ft.	
United States....	231	8.33	7.480	One cu. ft. of water at its maximum density, 39.1° Fahr., weighs 62.425 lbs. avoirdupois.
Imperial..........	277.274	10.00	6.242	

One Imperial gallon...............	= 1.2 U. S. gallons.
One U. S. gallon..................	= 0.833 Imperial gallon.
268.8 U. S. gallons of water.......	= 1 ton.
35.88 cubic feet of water..........	= 1 ton.
1 cubic inch of water.............	= .03613 pound.
Cubic feet of water x 62.425.......	= pounds.
Cubic inches of water x .03613.....	= pounds.
U. S. gallons x .13368.............	= cubic feet.
Cubic inches x .004329............	= U. S. gallons.
Cubic feet x 7.48..................	= U. S. gallons.
Cubic inches x .0005787...........	= cubic feet.
Pressure of a water column in pounds per square inch.........	= height of column in feet x .4335.
Pressure of a water column in pounds per square foot..........	= height of column in feet x 62.425.
One cu. ft. sea water at 62° Fahr..	= 64 pounds.
One cu. in. sea water.............	= 0.037037 pounds.

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